(3) Results of system analysis and economic calculation

1) Barka S.S. (275/132kV)

Two 250 MVA transformers will be installed in 1988 in due consideration of the results of the system analysis (refer to Chapter 13) and optimal standard capacities. (refer to 12.2.1 (7))

2) Khuwair S.S. (275/132kV)

Three 250 MVA transformers will be installed in 1988 in due consideration of the results of the system analysis and optimal standard capacities.

3) Khuwair S.S. (132/33kV)

Since 125 MVA Transformer is most advantageous according to economic calculation, 125 MVA transformer was selected. Two units of transformers will be installed in 1988.

4) Khabourah S.S. (132/33kV)

According to the results of economic calculation, 30MVA is most economical for the Khabourah S.S. However, since there is almost no cost difference between 30MVA and 45MVA, 45MVA is adopted in consideration of the series equipment (CB and LS), extention plan and maintenance.

Two units of transformers will be installed in 1988.

12.2 CONCEPTUAL DESIGN OF SUBSTATION APPARATUS

12.2.1 Substation design

(1) Design standards

Considering to harmonize and coordinate with the existing equipment in the capital and Batinah coast areas, following basic principles are established.

1) Must be able to meet the future demand increase.

2) Must minimize the voltage fluctuation and increase the supply reliability.

The design conditions shown in 11.2.1 were adopted for the design standards, conforming to the current standards adopted by MEW.

The standards and regulations for the conceptual design of this project were selected in the following standards and criteria.

IEC: International Electrotechnical Commission

JEC: Standard of the Japanese Electrotechnical Committee

JEAC: Japan Electric Association Code

JCS: Japanese Cable - maker's Association standard

(2) Increase of supply reliability

A substation service interruption in many cases greatly affects the consumers' benefit directly. The causes for power interruption can be attributable roughly to the maintenance work and equipment failure. All substation apparatus must be designed to minimize power interruption. The following reviews and countermeasures should be made in order to increase the reliability of substation:

1) A computer analysis is fully utilized for selection of substation sites and designing of substation equipment.

2) A review of insulation coordination as measures for lightning protection, thereby designing an economical and highly reliable system.

3) Selection of the optimum bus-bar system for avoidance of possible failures.

4) If a failure occurs to a 275kV line, a high speed reclosing method should be taken to increase the supply reliability.

5) Considering sandstorms, sand dust and high temperature, all equipment of 275 kV and 132 kV should be of indoor type except intake equipment and transformer.

6) On the drainage of each substation, land reformation is projected in consideration of floods that occur at the time of heavy rains.

(3) Insulation coordination

1) In order to protect equipment from abnormal voltage of lightning surge and power frequency, coordination of equipment insulation level will be adopted as follows.

a) For internal abnormal voltage (switching surge and persistent abnormal voltage, etc.), the insulation level of equipment itself will cope with said abnormal voltage.

b) For external abnormal voltage (lightning surge), the equipment will be protected by an arrester.

2) The type and quantity of the insulator strings have been determined on the condition that no flashover is to take place due to an internal abnormal voltage.

(4) Determination of a Basic impulse insulation level (BIL)

As described in preceding clause (3)-1)-b) since the equipment is protected from a lightning surge by an arrester, the BIL will be selected in order that it will withstand the switching surge and that it can be coordinated with the protection function of the arrester from a lighting surge. In other words, in order to maintain the protection tolerance of the arrester and equipment against lightening surge to be 20%, the BIL must be more than 1.2 times as much as the 100% sparkover voltage of the arrester. The specifications of arresters for the 132 and 275kV circuits are as follows if the same specifications as those of the existing equipment and JEC standards are applied.

Nominal Voltage	(kV)	132	275
Rated Voltage of Lightning Arrester	(kV)	126	266
Nominal Discharge Current	(kA)	10	10
100% Sparkover Voltage ①	(kV)	383	808
Residual Voltage	(kV)	403	851
Applied Basic Impulse Insulation Level ②	(kV)	550	1050
Margin of Insulation Level ②-①/②x 100 (%)	(kV)	30	23

During the survey at this time, it was unable to obtain exact statistical data of IKL (Isokeraunic Level - number of annual thunderstorm days), but the reviews were made assuming an IKL value of about 20 based on the figure 10 - 27 times during 4 years operation count of the arrester installed at the 132kV line of Al Falaj S.S.

(5) Design for salt contamination

The insulators will be selected according to the design values specified in M.E.W. Standard "Insulator Leakage Clearance for Existing Facilities: 45 mm/kV (Line Voltage)".

The insulators to be selected will have withstanding capability that correspond to the insulator leakage clearance for existing equipment. They will be aerodynamic type insulators, as described in paragraph 11.2.4. Bushings will be selected in accordance with the same criteria. This result are as follows.

Nominal voltage	Specification of the insulator	Surface leakage distance (mm)	Leakage distance per kV (mm/kV)
132	Aerodynamic type 330 mmφ x 21	6,195	47
275	" 380 mmφ x 37	12,580	46

(6) Determination of bus-bar system

The bus-bar system was determined as shown in Table 12.6 based on the number of lines, rated current capacity and operation problems referring to the bus-bar system currently used by MEW and a bus-bar system of substations on Japanese trunk lines.

The reasons for adopting the 4CB system for the Barka P.S. and Khuwair S.S. are easy system separation or coordinated operation with other systems, easy applicability of irregular operation during the installation work,

(7) Main transformer, Circuit breaker and Power capacitor

Since the neutral points of both 275 and 132 kV circuits are directly grounded, an auto transformer was adopted as a tie to connect 60 MW circuits. It has an economical advantage to be 80% of the price of 2-winding transformer.

Each transformer is provided with an on-load-tap-changer with a tap range of +5 - -15% as is the case of existing transformers.

As for the standardized size of transformer for 275/132 kV, 250 MVA is selected in consideration of the scale of Barka P.S., and possible demand growth.

The 31.5 kA rating is selected for a circuit breaker of 275 kV and 132 kV in due consideration of the results of the short-circuit current of the power system. However, this value should be reviewed at the stage of detailed design to meet with future system expansion.

Table 12.6 Bus system of major P.S. and S.S.

Power station, Substation		Voltage	Bus System	Remarks
Existing and being planned	AL FALAJ S.S.	132(kV)	-	
	WADI ADAI S.S.	"	Main and inspection bus (1CB)	
	GHUBRAH P.S.	"	Double bus (1CB)	
	RUSAIL P.S.	"	Main and inspection bus (3CB)	
	SEEB PALACE S.S.	"	-	
	BARKA S.S.	"	Double bus (1CB)	
Newly installed	BARKA P.S.	275	" (4CB)	large number of lines. Easy irregular operation during the installation work
	BARKA S.S.	"	" (1CB)	
	KHUWAIR S.S.	"	" (1CB)	
	"	132	" (4CB)	Advantageous to apply to system linkage
	KHABOURAH S.S.	"	" (1CB)	

Also, based on a computer analysis, installation of 2 x 20 MVA capacitors are determined at Khuwair S.S. for voltage regulation.

(8) Fire protection

For fire protection of large capacity transformers, the following facilities will be furnished.

- The transformer will be enclosed in three sides concrete walls for blast proof.

- Water spray fire extinguishers for fire fighting

- Oil dam for prevention of oil outflow

(9) Monitoring system and supply operation

For a monitoring system for Khuwair, Barka, and Khabourah S.S., a remote monitoring system will be adopted in accordance with the existing one, and these substations will be constantly monitored from Medinat Qaboos S.S.

Therefore, the engineers will be sent from time to time to these substations from the waiting station for maintenance and operation.

It should be noted that, when Barka P.S., Copper mine P.S. and Sohar P.S. start commercial operation, five large-capacity thermal power plants will be operated under a single electrical power system. To operate the system economically, and to deal with interruption adequately, an automatic load dispatching control system shall be introduced.

MEW intends to establish the said control center in Medinat Qaboos S.S. To the control center, the following data and information will be sent from each power station and substation by means of a power line carrier.

Data and information for a load dispaching center

Observation Item	Contents	P.S. / S.S.
On/off Indication	Circuit Breaker of 275 kV, 132 kV	P.S. and S.S.
	Disconnecting Switch of 275 kV, 132 kV	P.S. and S.S.
Meters and Recorders	Gross output power of P.S.	P.S.
	Effective and reactive power on 275, 132 kV lines	Receiving end of the Line
	Load on transformer of 275/132 kV, 132/33 kV	S.S.
	System Frequency	Important P.S./S.S.
	System Voltage	Important P.S./S.S.
	Load of 33 kV side	P.S. and S.S.
Alarm/ Indicator	Protection Relay	No-man S.S.

(10) Protection device

A protection system should be selected putting emphasis on the minimization of a shut-down area, coordination with main power systems and reliability. Besides, this protection system should be compatible with the present conditions of MEW networks.

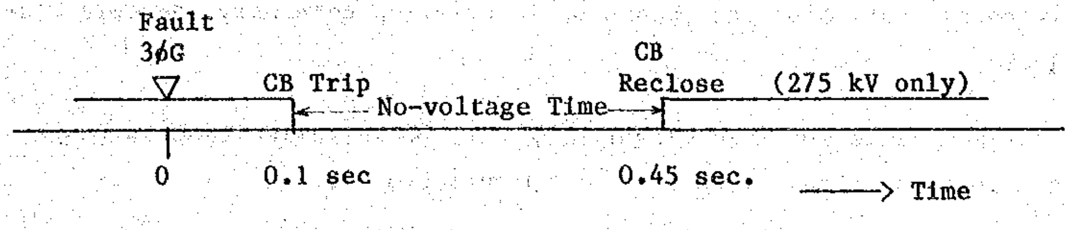
Furthermore, care must be paid so that there is no section left unprotected.

The outline of protection equipment for transmission is as shown below. This transmission system is a directly grounded neutral system. Protections will be composed of the following four (4) functions.

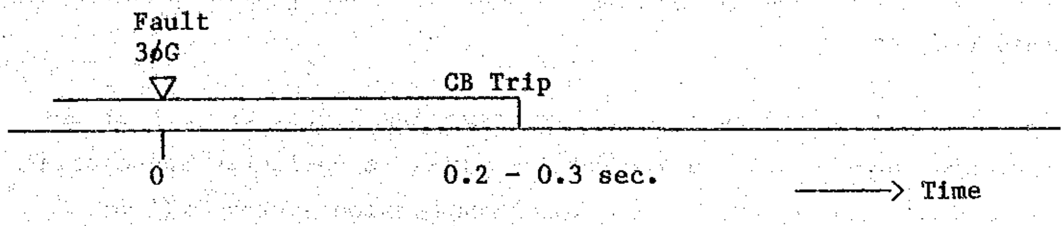
o Main short-circuit relay ⟶ Power line carrier relaying system
o Main ground relay ⟋ (Directional distance relaying system)
o Back up short-circuit relay ⟶ Directional distance relay + Over
o Back up ground relay ⟋ current relay system

The fault sequence applied to the transmission line is as follows:

1) Action of the Main Relay



2) Action of the Back up Relay



12.2.2 Equipment of each substation

(1) Figures 12.7 through 12.14 show the skeleton diagram and equipment layout of each substation.

(2) In designing substations the following points were especially examined from the viewpoint of operation and maintenance.

1) The arrangement of equipment will be made in the same manner as the existing facilities and standardized in order to realize quick and exact operation of the equipment.

2) The GIS system will be applied to the indoor equipment for 275kV and 132kV and the cubicle system by VCB or GCB will be applied to the indoor equipment for 33kV.

3) A cable duct system will be used for the outdoor installation of power cables in view of reliability.

12.3 CONCEPTUAL DESIGN OF TELECOMMUNICATIONS EQUIPMENT

12.3.1 Design conditions

The following were set as the basic conditions for conceptual design of the telecommunications equipment:

(1) A power line carrier system is adopted as the telcommunication system in consideration of the amount of information necessary for this project.

(2) Telephone sets for load dispatching will be installed between power stations and substations related to this project.

(3) The telecommunications equipment which will be counted in this Project are only those to be installed for the transmission line sections of this Project.

(4) All information and data about the operating status of each of the proposed power station and substation will be collected and displayed at Medinat Qaboos S.S. A new data transmission system will be installed for this purpose.

(5) Teleprotection equipment will be installed on all transmission lines of 132kV or higher voltage as related to this Project.

12.3.2 Conceptual design

Based on the conditions outlined in the preceding clauses, a conceptual design of telecommunication equipment for this project is made as follows.

(1) Power line carrier equipment

Two circuits of the power line carrier equipment (with 4 KHz band) of 2-channel type will be installed between power stations and substations. The connecting form will be an inter-line metallic system, meeting with the existing systems. The carrier frequency must be determined upon examining the existing one at the stage of detailed design.

(2) Power line carrier relaying equipment

Signal transmission equipment for protection of the transmission line will be installed between all power stations and substations related to this Project.

(3) Signal transmission equipment

To display the information on P.S. and S.S. planned in this Project at the Medinat Qaboos S.S., signal circuits will be installed between them. The signal transmission system will be installed under other projects.

(4) Telephone system

A telephone network for load dispatching is to be installed covering all related power stations and substations.

(5) Power supply equipment

The power supply equipment for the telecommunication equipment needed by this project is to be a DC power system consisting of a floating charging device and batteries.

Fig. 12.15 and Fig. 12.16 shows the outline of these telecommunication equipment.

12.4 CONCEPTUAL DESIGN OF BUILDING AND FACILITIES

The following switching facilities and administration buildings are planned for the proposed substations and switching stations. The switching stations and relay rooms for 275kV, 132kV, and 33kV will be provided with underground facilities to accommodate the cables.

(1) Barka P.S.

275kV Switchgear
Reinforced concrete construction, 1 story, basement room, 1 building, 2,660 m^2

(2) Barka S.S.

275kV Switchgear
Reinforced concrete construction, 1 story, basement room, 1 building, 1,400 m^2

(3) Khuwair S.S.

132kV, 33kV Switchgear
Reinforced concrete construction, 1 story, basement room, 1 building, 1,540 m^2

275kV Switchgear, Relay room, Office
Reinforced concrete construction, 1 story, in part basement room, 1 building, 2,310 m^2

(4) Khabourah S.S.

132kV, 33kV Switchgear, Relay room, Office
Reinforced concrete construction, 1 story, in part basement room, 1 building, 2,350 m^2

Fig. 12·7 BARKA SUBSTATION SINGLE LINE DIAGRAM

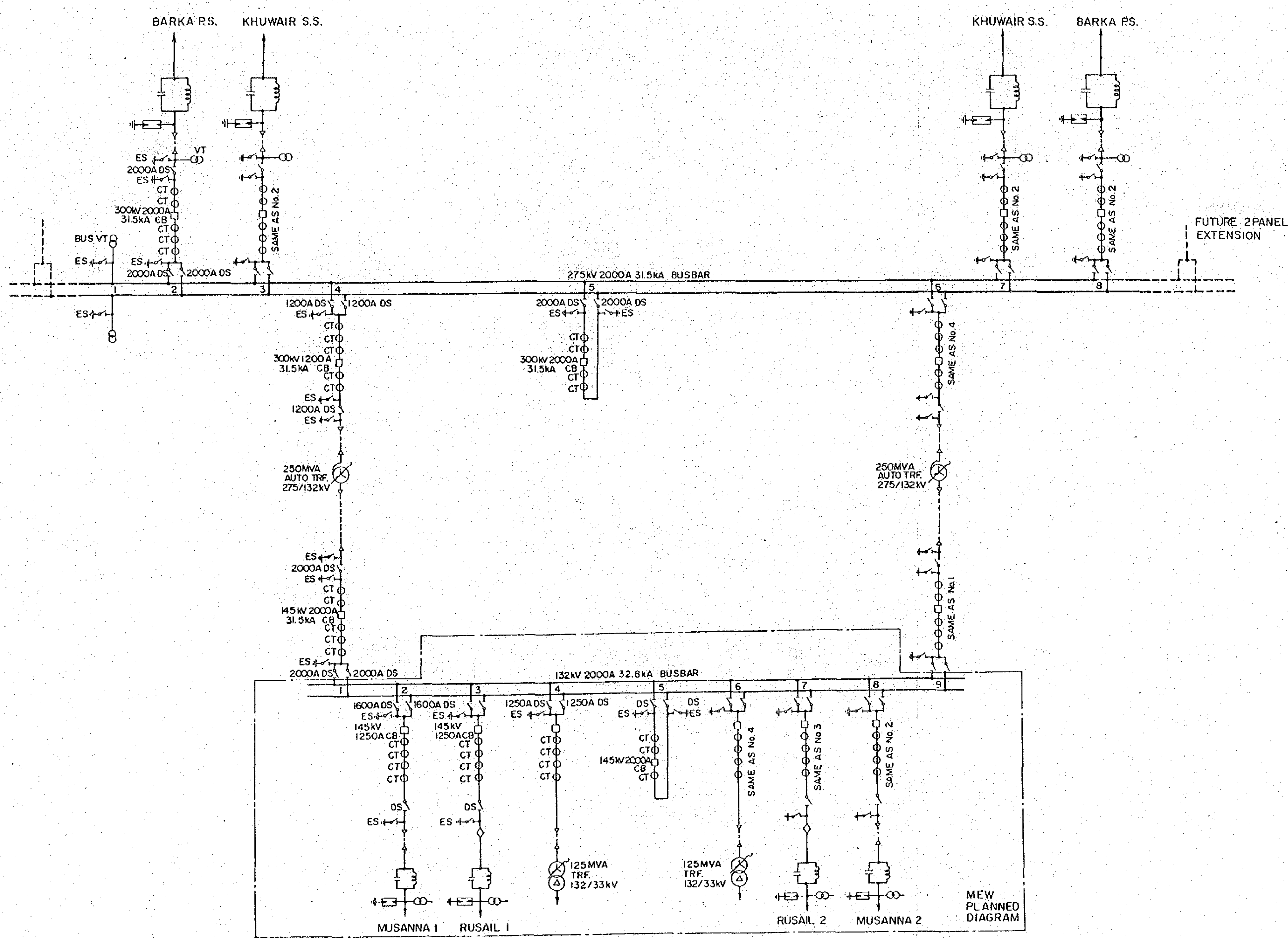


Fig.12·8(1) KHUWAIR SUBSTATION SINGLE LINE DIAGRAM

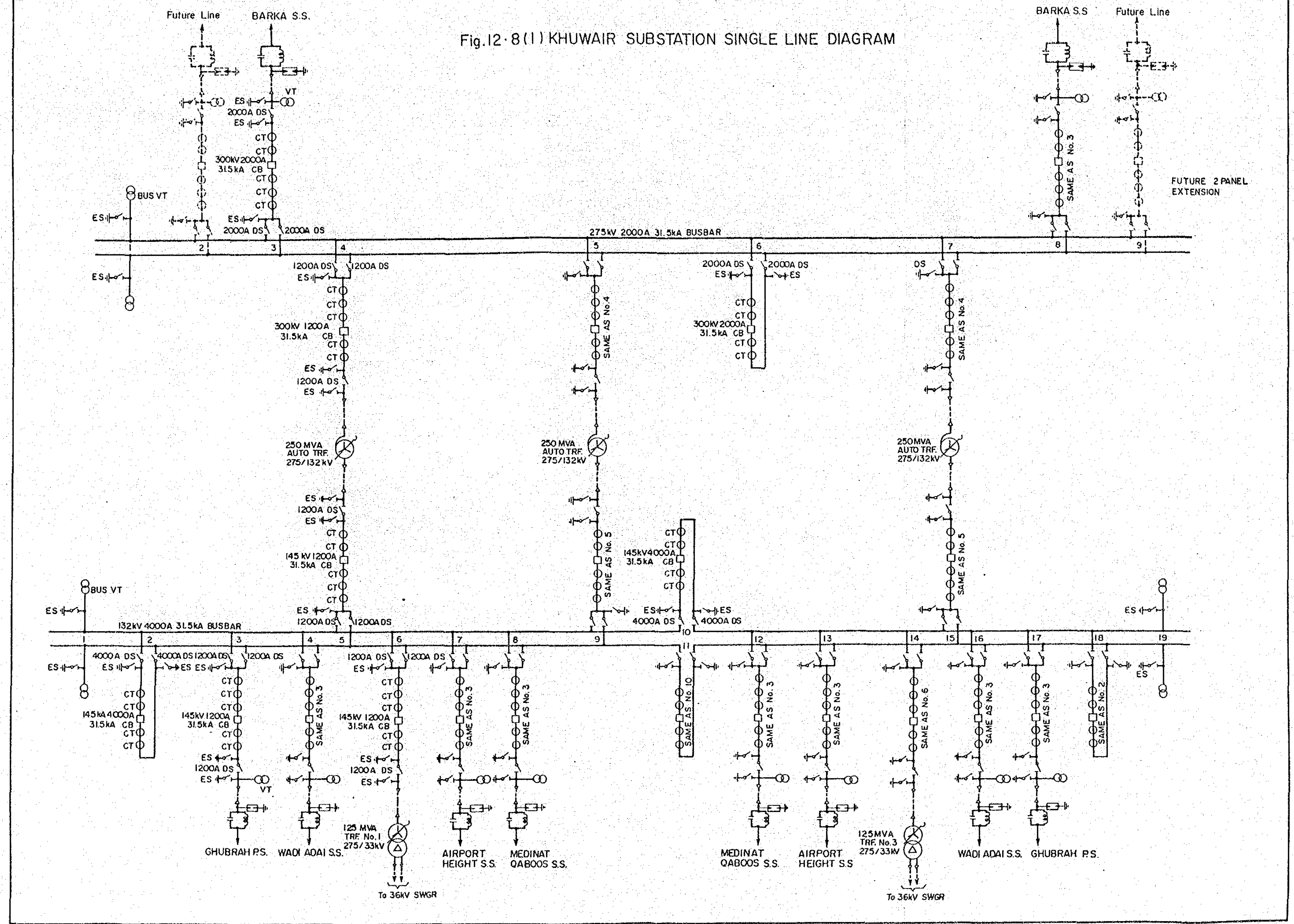


Fig. 12·8 (2) KHUWAIR S.S. SINGLE LINE DIAGRAM

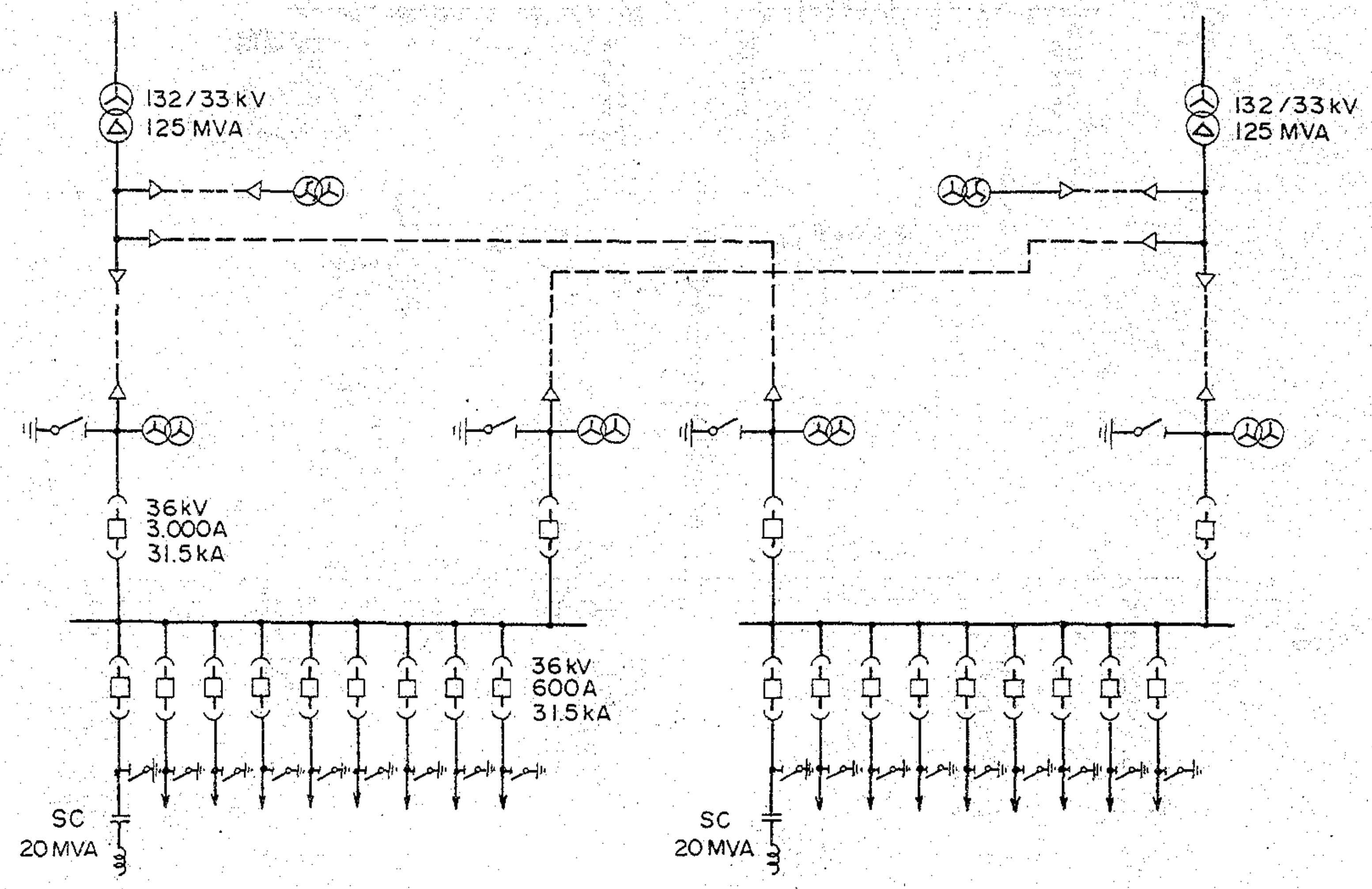


Fig. 12・9 KHABOURAH SUBSTATION SINGLE LINE DIAGRAM

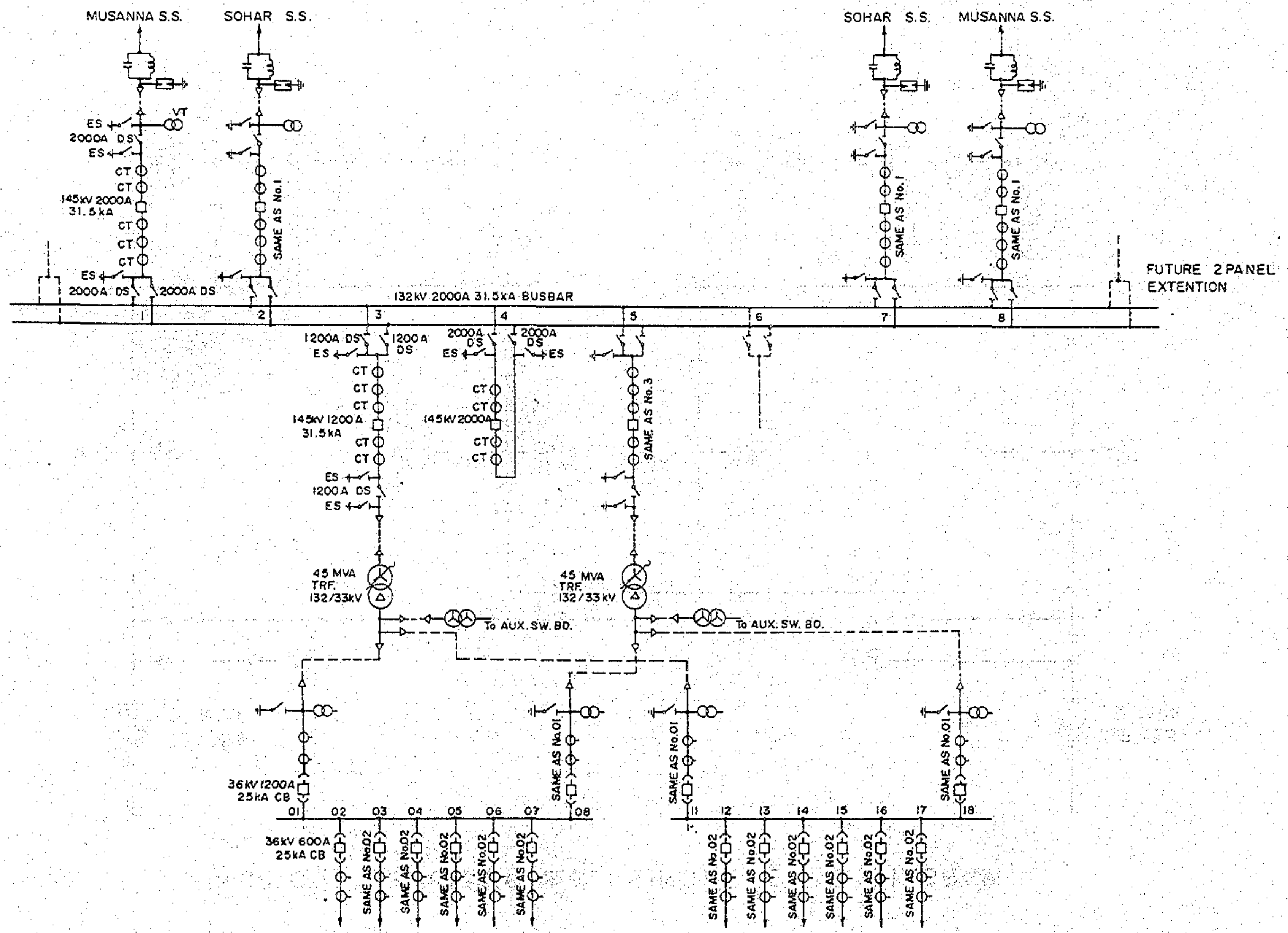


Fig. 12·10 LAYOUT FOR BARKA 275/132/33kV SUBSTATION

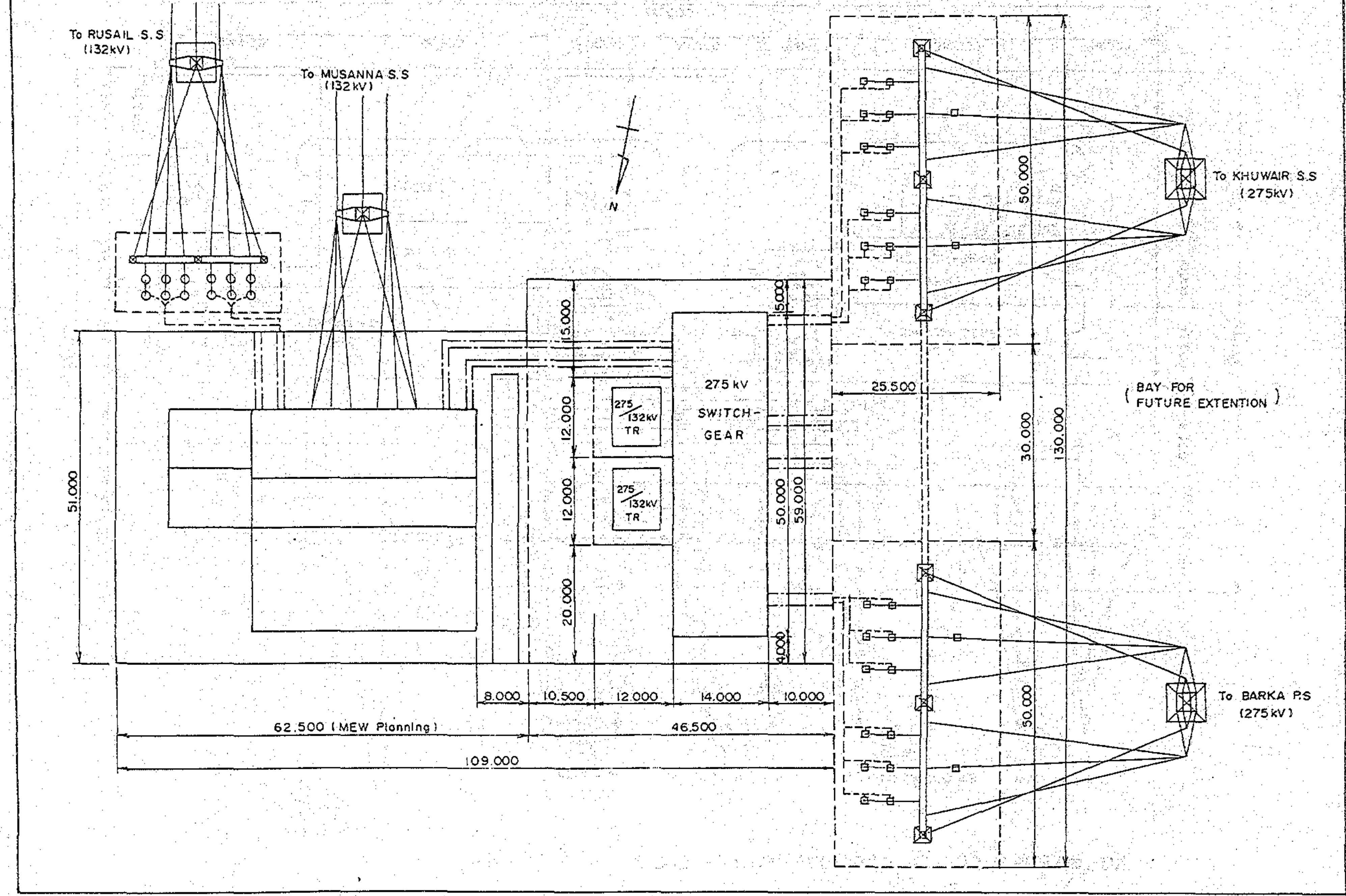


Fig. 12 · 11 LAYOUT FOR KHUWAIR 275/132/33kV SUBSTATION

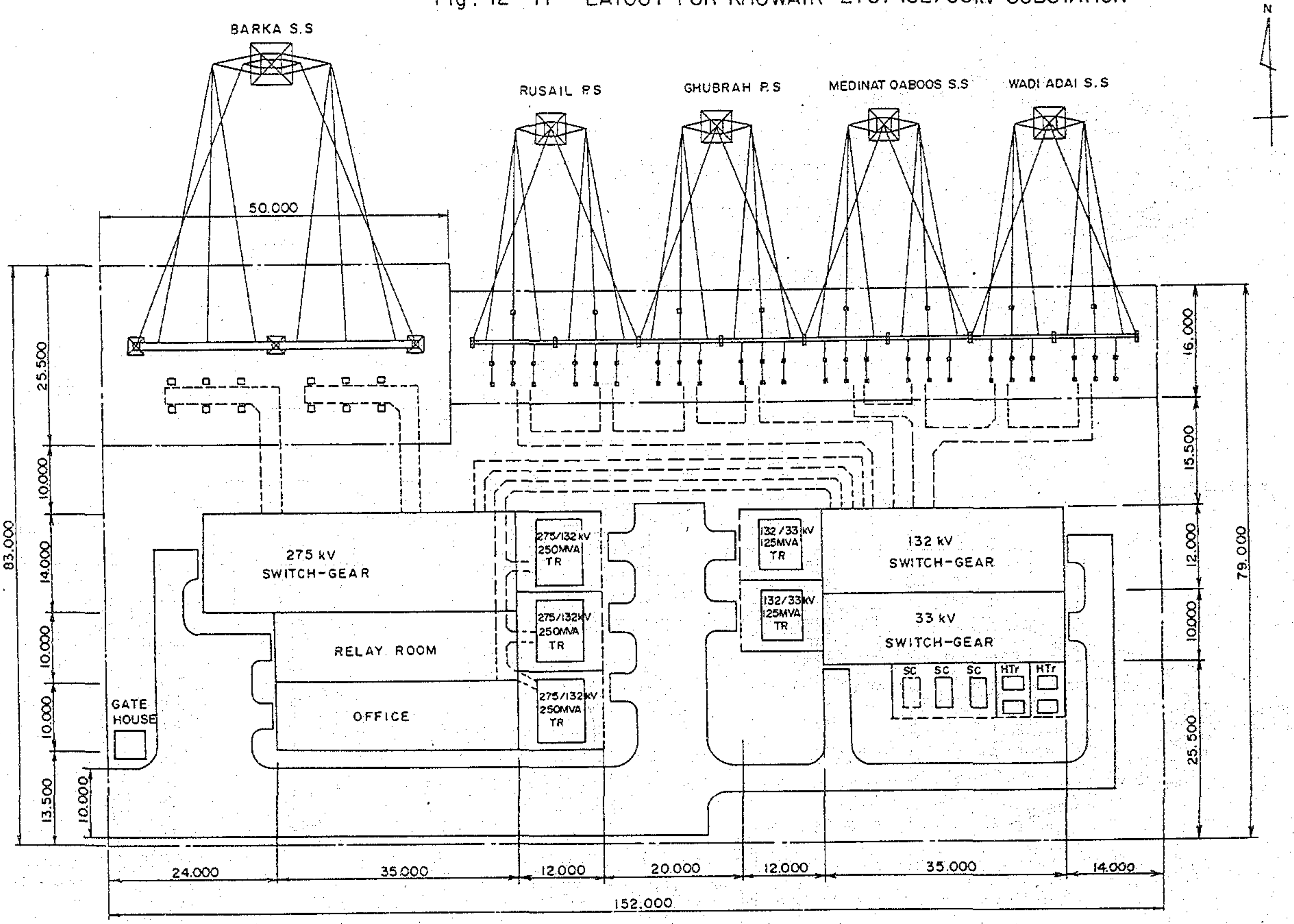


Fig. 12·12 SITE LAYOUT FOR KHABOURAH 132/33kV SUBSTATION

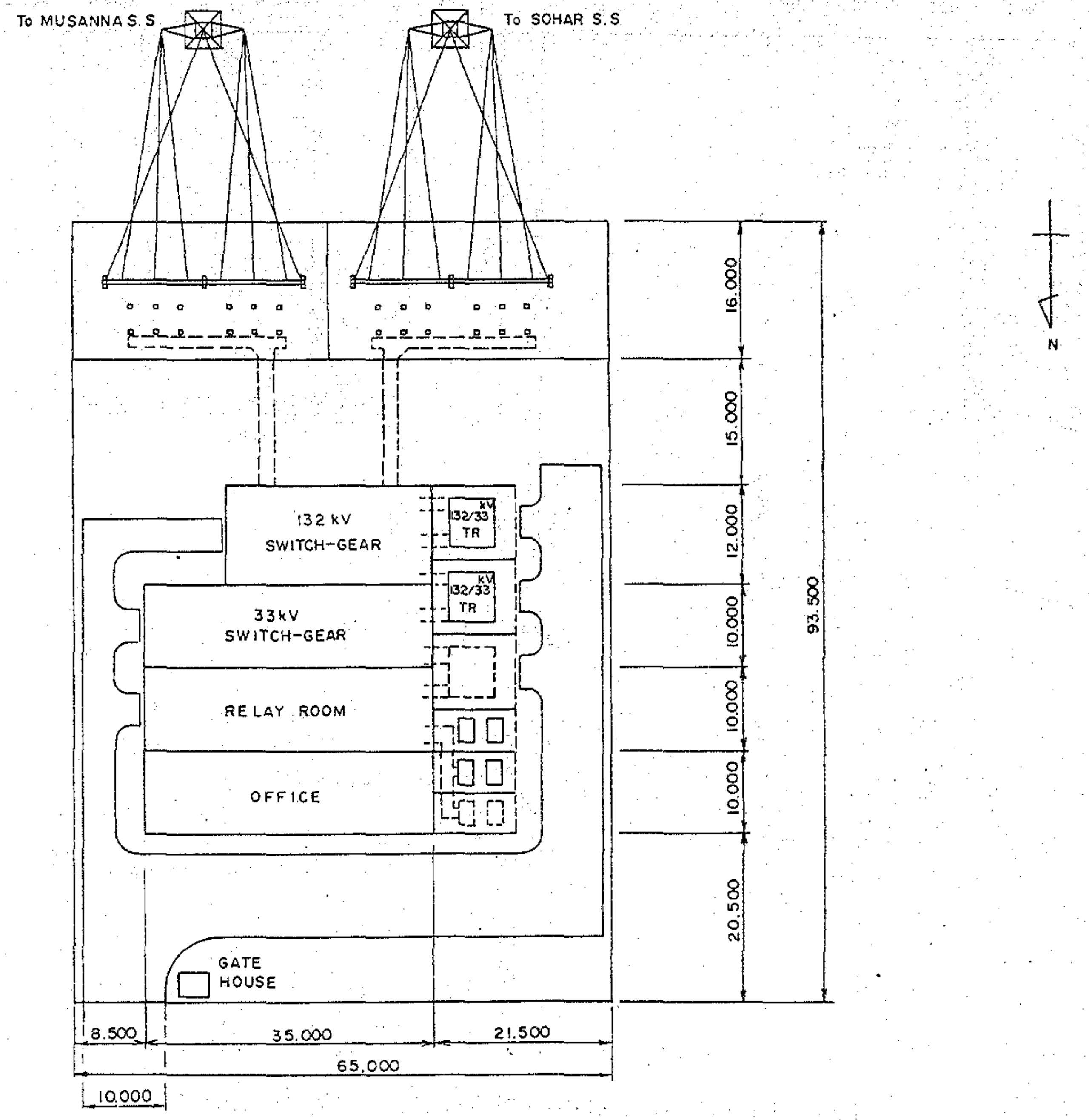


Fig. 12 · 13 GENERAL ARRANGEMENT (DRAWING OF 275kV INCOMING LINE)

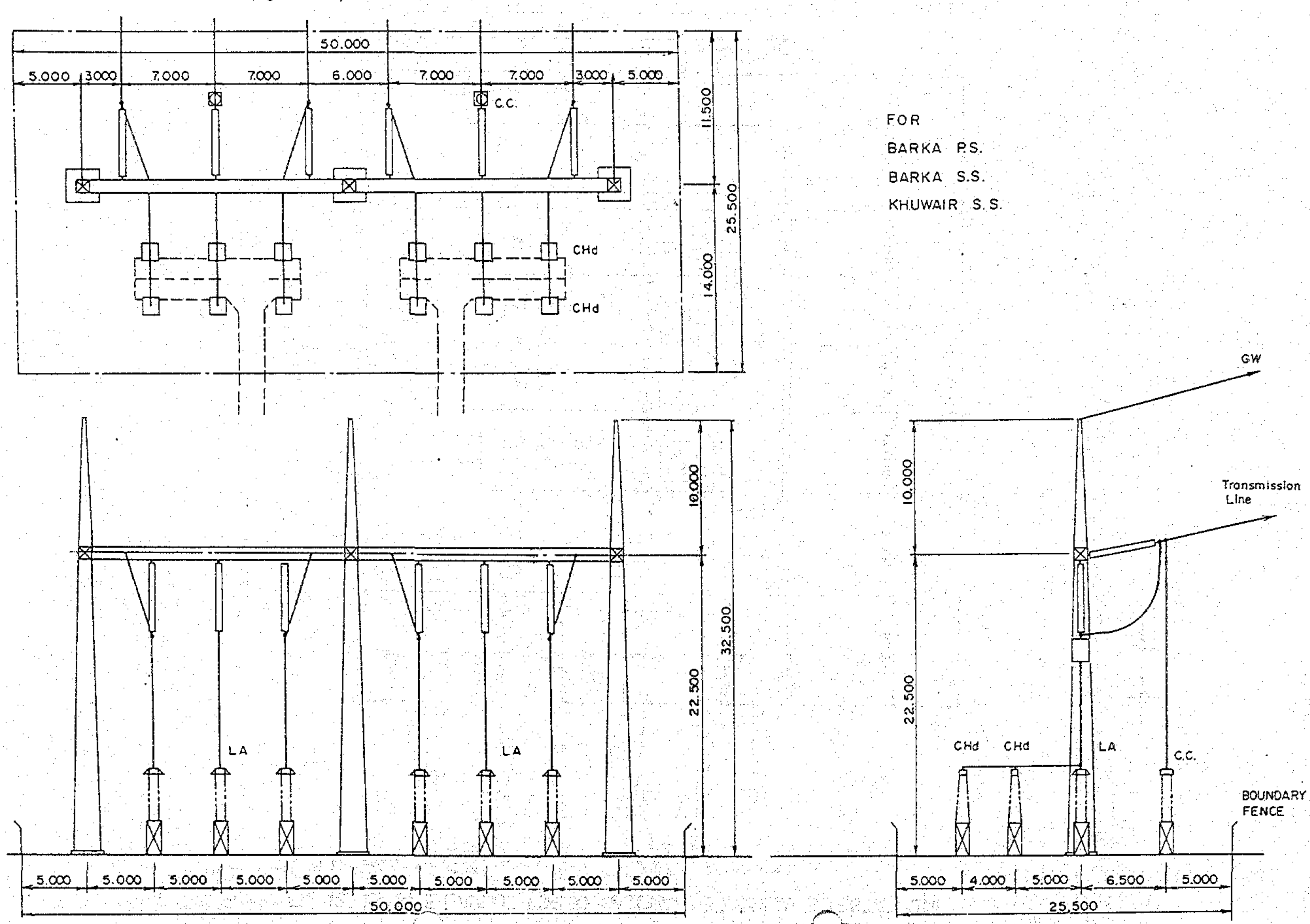


Fig. 12·14 GENERAL ARRANGEMENT (DRAWING OF 132kV INCOMING LINE)

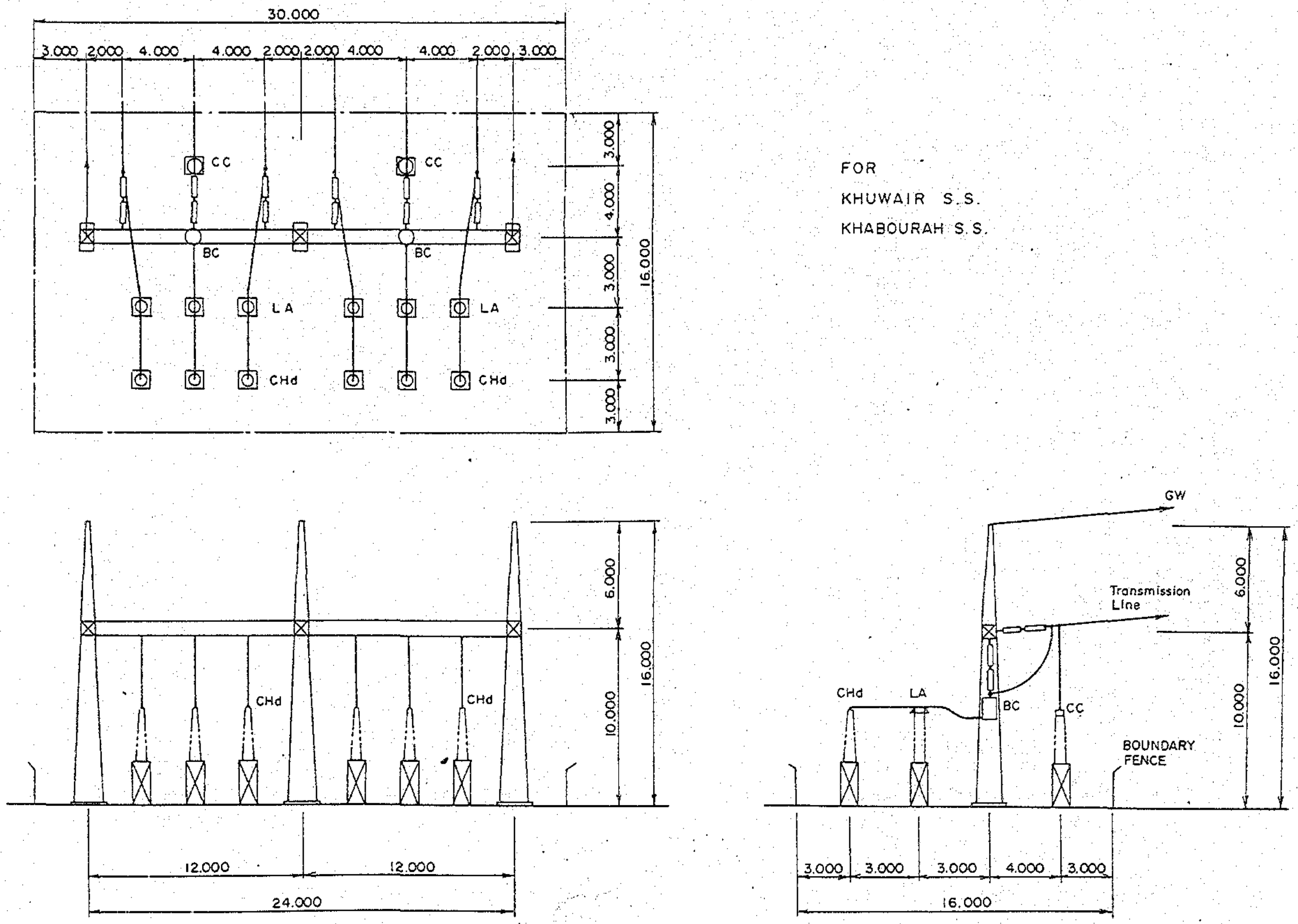


Fig.12.15 CONSTITUTION OF TELECOMMUNICATION FACILITY

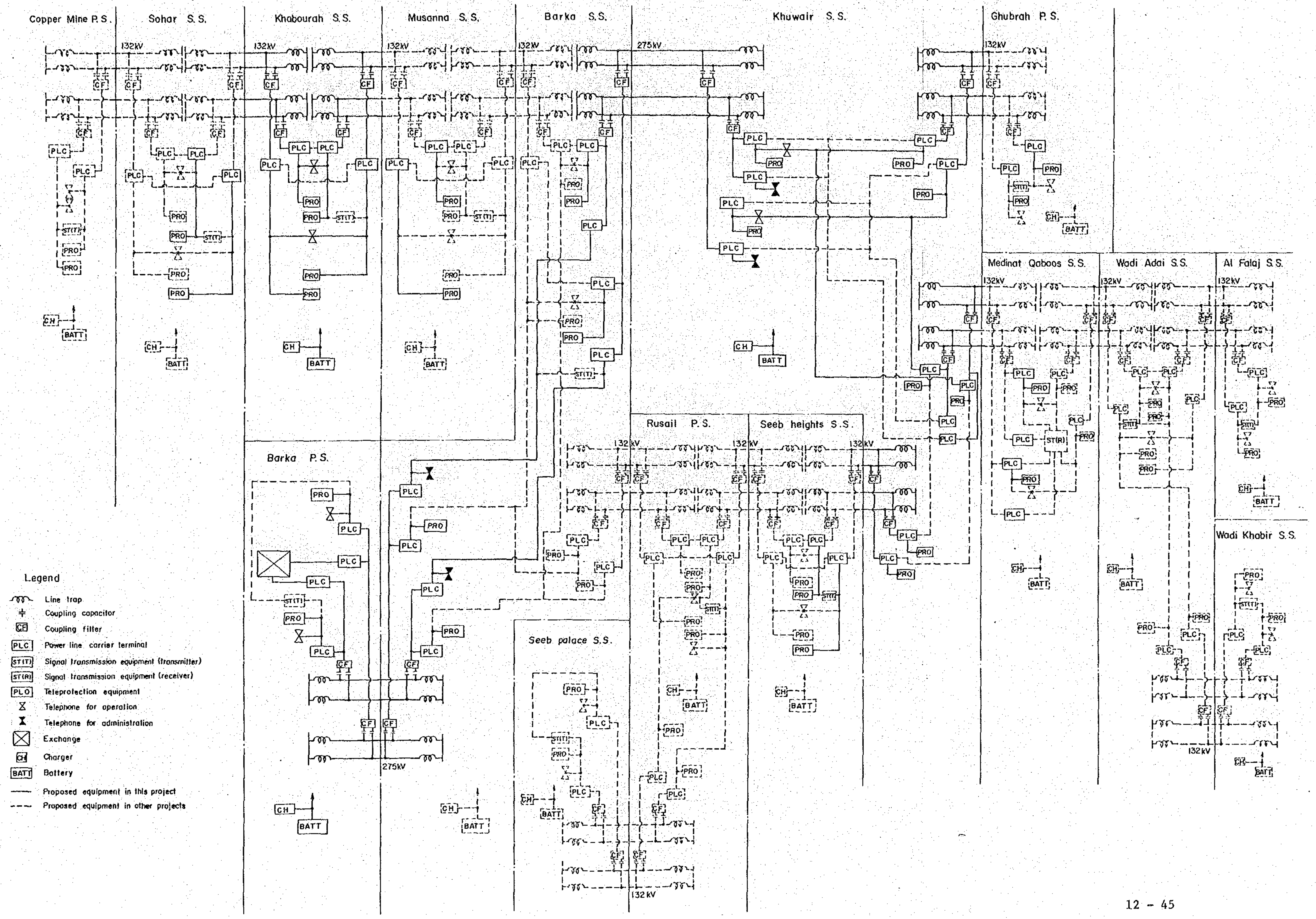
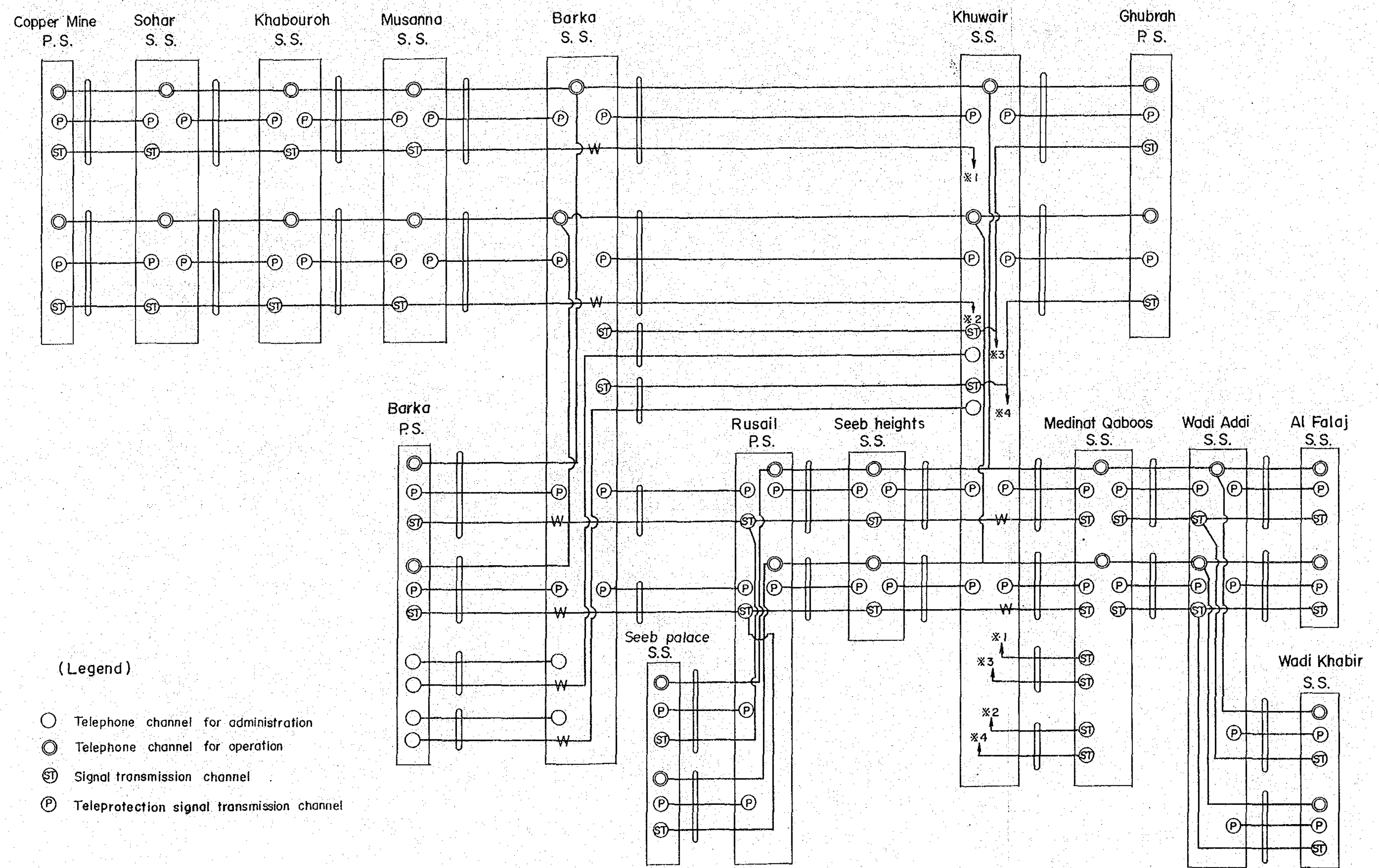


Fig. 12.16 TELECOMMUNICATION CIRCUIT DIAGRAM



(Legend)

- ○ Telephone channel for administration
- ◎ Telephone channel for operation
- ⓈⓉ Signal transmission channel
- Ⓟ Teleprotection signal transmission channel

CHAPTER 13 POWER SYSTEM ANALYSIS

CHAPTER 13 POWER SYSTEM ANALYSIS

13.1 OUTLINE OF POWER SYSTEM

The power system of Oman consists of 132 kV transmission lines and 33 kV subtransmission lines. The power is consumed mostly in the capital area and major power stations are located in this area. As the power demand increased, the power system has been expanded, and at present a plan is made to interconnect the Batinah coast where small isolated power systems scatter and the capital area by 132 kV transmission lines. By 1989 at which the interconnection lines will be completed, the 132 kV transmission lines will have been expanded to 500 km or longer, configurating an unified power system.

13.2 TRANSMISSION PLAN OF BARKA P.S.

13.2.1 Substation plan

(1) Barka P.S.

275 kV transmission lines are to be introduced at the first time to connect the Barka P.S. and existing power system. Therefore, transformers (275/132 kV) are newly installed in Barka S.S. which is planned under the Project.

(2) Khuwair S.S.

The Khuwair S.S. (275/132/33 kV) is newly constructed in the capital area to connect Barka S.S. with the load center by 275 kV lines.

13.2.2 Transmission line plan

(1) Barka P.S. - Barka S.S.

Two lines of 275 kV are newly constructed between Barka P.S. and Barka S.S. (13km).

(2) Barka S.S. - Khuwair S.S.

Two lines of 275 kV are newly constructed between Barka S.S. and Khuwair S.S. (47km).

As a result of newly constructing the said substations and transmission lines, the transmission system in the capital area will be configurated by a loop system consisting of new 275 kV lines and existing 132 kV lines.

13.3 POWER SYSTEM ANALYSIS

The power system analysis have been performed in order to examine the characteristics of the power system associated with newly added lines and power station. The objective themes for the analysis are as follows:

- Power flow and voltage study associated with the expansion of the power system
- Selection of transmission voltage for Barka P.S.
- Determination of tie-transformer capacity
- Power system stability study
- Short-circuit study
- Site selection for new power station after construction of Barka P.S.

13.3.1 Premiss for calculation

Premiss for the power system analysis are set as follows.

(1) Objective years and items of calculation

Table 13.1 gives the expansion program of power stations and transmission lines and the system calculation items necessary for the expansion.

Table 13.1 Expansion program and calculation items

Year	Power Stations (MW x Unit)		Transmission lines and Substations	Calculation items
1988	Barka	80 x 2	Barka P.S. - Barka S.S. (275 kV 2 Lines) Barka S.S. (275 kV/132 kV)	Power flow
1989	Barka	80 x 2	Barka S.S. - Khuwair S.S. (275 kV 2 Lines) Khuwair S.S. (275 kV/132 kV/33 kV) Khabourah S.S. - Sohar S.S. (132 kV 2 Lines)	Power flow
1990	Barka	80 x 2 60 x 2	-	
1991	Barka	80 x 1 60 x 1	-	Power flow, Stability
1992	Khabourah*	80 x 2	-	
1993			-	
1994	Khabourah*	80 x 2	-	
1995	Khabourah*	80 x 2	-	Power flow, Stability, Short-circuit current

* Supposed sites of new power station after Barka P.S.

(2) Power flow and voltage calculation

The calculations of the power flow and voltage are carried out by setting the operation conditions of power system as follows.

- System voltage to maintain	95 - 105%
- Operating voltage of generator	100 ± 5%
- Operating power factor of generator	Above 0.80
- Tap ratio of transformer	1.00 ± 0.075
- Power factor of feeder load	0.85
- Load time	Peak hours

In order to maintain the system voltage within the range mentioned above, static condensers are to be applied to the appropriate substations.

Based on the power flow study, overloading of each transmission line is examined according to the rated current carrying capacity of the line as given in Table 11.1.

(3) *Voltage selection of transmission line*

The three alternatives of 220 kV, 275 kV and 330 KV as next higher voltage of existing 132 kV are chosen for the object of comparison studies to select the optimum voltage for the transmission line connecting Barka P.S. - Barka S.S. - Khuwair S.S.

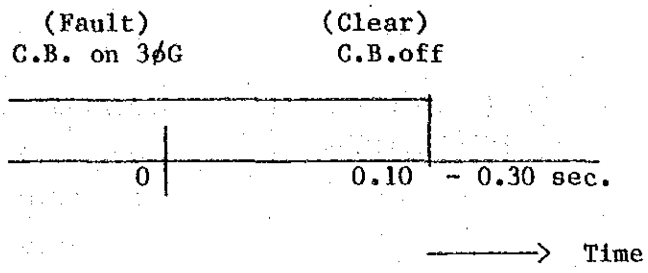
(4) Determination of tie-transformer capacity

As a result of an introduction of 275 kV to the system, the study on the capcity of tie-transformer to connect the existing 132 kV network and the 275 kV network is carried out.

(5) System stability calculation

1) Fault sequence

Power system stability calculation is performed on the power transfer of Barka P.S.
As a disturbance on the power system, three-phase ground fault (3ϕG) is applied to the 275 kV line of the Barka P.S. - Barka S.S. - Khuwair S.S. and the perturbations of all generators after a system disturbance is examined.
The fault resistance is taken as zero and the high-speed reclosing of the faulty line is not assumed to give a severe impact on the network in this calculation. The fault sequence applied to the line is shown in th following illustration.
For the fault clearing time, 0.10 seconds were used provided that the protective relay operates normally. However, 0.15 sec. and 0.30 sec. were also used for one case of calculation respectively assuming the teleprotection failures.



2) Voltage Characteristics of Load

The voltage characteristics of load differ depending on the type of load. The calculation used the constant-impedance characteristic to simulate the lamp load and also the constant -current characteristics to simulate the motor load since the MEW system has a large percentage of the induction motor load.

The following shows the formulas made to express such characteristics.

(a) Constant-impedance characteristics

Active power $P = Po\ (V/Vo)^2$

Reactive power $Q = Qo\ (V/Vo)^2$

(b) Constant-current characteristics

Active power $P = Po\ (V/Vo)^1$

Reactive power $Q = Qo\ (V/Vo)^2$

(6) Short-circuit current calculation

The short-circuit current was calculated in the state that all generators of the system are in parallel operation. The generators and their constants used for the calculation are as follows.

1) Generator constant

Power station	Total rated capacity of generators (MVA)	Transient Reactance Xd' (%)
Barka	1,155*	20.0
Rusail	688	19.8
Ghubra(33kV)	96	16.5
Ghubra(132kV)	258	16.5
Copper Mine	210	16.5
Khabourah	790	20.0
Sohar	75	16.5

(* 140x5, 115x2, 75x3)

2) Impedance voltage of transformer

Voltage ratio (kV)	Impedance Voltage (%)
(Planned to be installed)	
275/132 (Step down)	12.0
275/14 (Gen. step up)	12.0
132/33 (Step down)	10.0

(Existing transformers)

Data supplied by MEW are used.

(7) Location for a new power station

The location for a new power station after completely developing the Barka P.S. is studied. This study is made to find more advantageous location for the power development based on the power flow on the primary transmission lines, bus voltage of the system and load distribution.

(8) Demand of substation and impedance map

The peak demand of each substation and the impedance map used for the study are given in Table 13.2 and in Fig 13.1, respectively.

Table 13.2 Demand of Substations

(MW)

Year / Sub-Stations	1988	1989	1990	1991	1992	1993	1994	1995
Al Falaj	84	94	105	114	122	129	136	143
Wadi Khabir	84	94	105	114	122	129	136	143
Wadi Adai	83	94	104	114	121	129	135	143
Qaboos	76	81	95	110	120	131	136	141
Khuwair	50	65	85	105	120	131	136	141
Ghubrab	89	96	103	110	115	120	125	130
Airport H.	40	80	95	110	117	124	132	141
Rusail	187	191	196	203	211	220	228	237
Seeb Palace	48	50	53	56	59	62	65	69
Barka	40	46	50	55	61	68	76	84
Musanna	17	19	22	25	29	33	38	44
Rustaq	21	24	27	32	36	42	48	55
Suwaiq	21	24	28	32	37	42	49	56
Khabourah	13	16	18	20	24	27	31	36
Saham	23	27	32	37	43	49	56	65
Sohar	30	37	44	50	57	66	76	87
Shinas	8	10	11	13	15	17	20	23
Copper Mine	17	17	17	17	17	17	17	17
Buraimi	56	66	75	83	95	106	116	131
Ibri	44	52	61	68	78	87	96	109
Grand Total	1031 (853)	1183	1326	1468	1599	1729	1852	1995

( ) : Unified network of the Capital Area

(Note)

The system analysis is devided into two stages, original stage and revised stage.
The difference between the both stages is as follows:

Stage	Network conditions
Original stage	a. Output of Barka P.S.: 720 MW (Corresponding to Type-A) b. Airport heights S.S. is excluded c. Transformation ratio of Khuwair S.S.: 275/132 kV and 275/133 kV

Power flow studies in 1988 and 1989 were performed under these conditions (Figs. 13.2 - 13.4).

Revised stage	a. Output of Barka P.S.: 740 MW (Corresponding to Type-F) b. Airport heights S.S. is included c. Transformation ratio of Khuwair S.S.: 275/132 kV and 132/33 kV

System calculations in 1988 and 1989 were performed under these conditions (Figs. 13.5 - 13.18).

13.3.2 Results of analysis

(1) Power flow and voltage calculation

The result of the calculations is shown in the form of power flow diagram, Fig 13.2 to Fig 13.6. The transitions of static condensers for voltage correction and transmission losses obtained by the calculations are given in Table 13.3.

Table 13.3 Result of Power Flow Studies

Item \ Year		1988	1989	1991	1995
Power demand (MW)		1,031	1,183	1,468	1,995
Active power losses (MW) (Loss ratio) (%)		4.74 (0.31)	7.24 (0.61)	13.83 (0.93)	30.98 (1.53)
Reactive power losses(MVar)		176.36	164.95	308.47	498.52
Required Static Condensers (MVA)	Al Falaj	25	15	30	50
	Wadi Khabir	25	15	30	50
	Wadi Adai	10	10	25	50
	Qaboos	10	10	25	35
	Airport H.	-	-	-	25
	Khuwair	-	-	30	45
	Rusail	25	-	-	45
	Rustaq	-	-	-	20
	Buraimi	-	-	15	40
	Ibri	-	-	15	55
	Total	95	50	170	415

1) System in 1988

Fig. 13.2 shows the power flow at the time of normal operation in 1988. The output of Barka P.S. in this year is 160 MW (80 MW x 2) and the power is transmitted through the two lines of 275 kV connecting Barka P.S. and Barka S.S. The amount of static condenser required for the system voltage correction is calculated at 95 MVA (Table 13.3).

Even if one line is out of service, there will be no overloaded line.

2) System in 1989

Fig. 13.3 and Fig. 13.4 show the power flow at the time of normal operation in 1989. Since the output of Barka P.S. will have increased to 320 MW (80 MW x 4) in this year, the expansion of 275 kV lines spread from Barka S.S. will be required.

Fig. 13.4 shows the power flow when the 275 kV line is not yet expanded, and Fig. 13.4 shows the power flow for the case of newly constructing Khuwair S.S. and connecting it with Barka S.S. with 275 kV lines.

In Fig. 13.4, there will be no overloaded line even when one line is out of service. On the other hand, in Fig. 13.3, the section between Rusail S.S. and Ghubrah S.S. is a heavily loaded line (ACSR 240 mm^2), and if one of the related lines in this section is out of service, the power flow of this section exceeds its permissible limit (144 MW/2 lines).

Accordingly, Khuwair S.S. and the two lines of 275 kV between Barks S.S. and Khuwair S.S. must be constructed.

The amount of static condenser required for the system voltage correction is calculated at 50 MVA in the network expanded by 275 kV lines (Table 13.3).

3) System in 1991

Fig. 13.5 shows the power flow at the time of normal operation in 1991. In this year, Barka P.S. will have been completely developed and its output will have reached to 740 MW. There will be no overloaded line while the network is operating normally. But, it is observed that Khuwair - Wadi adai and Khuwair - Qaboos lines are heavily loaded.

If one of these lines is out of service, the remaining parallel line will be overloaded.

Also Rusail - Airport heights lines are heavily loaded, but even with one of these lines being out the other lines will be not overloaded. The amount of static condenser required for the system voltage correction is calculated at 170 MVA (Table 13.3).

4) Power flow in 1995

Fig. 13.6 shows the power flow at the time of normal operation in 1995. For this year, Ghubrah P.S. is assumed to be the next power station after the construction of Barks P.S. and the power flow calculation was performed for a case of the output being 480 MW.

There will be no overloaded line while the network is operating normally. But, Khuwair-Wadi adai, Khuwair-Qaboos and Rusail-Airport heights lines are heavily loaded. If one of these lines is out of service, the remaining parallel line will be overloaded.

The amount of static condenser required for the system voltage correction is calculated at 415 MVA (Table 13.3).

(2) Selection of transmission voltage

Economic comparison of three voltage classes of 220 kV, 275 kV and 300 kV for the transmission lines that connect the Barka P.S., the Barka S.S. and the Khuwair S.S. were made. The power flow calculation of 1995 was used as the base for the comparison study. Comparison of the transmission losses and construction cost of the lines and associated substations including static condensers of each voltage class are given in Table 13.4. The power flow on each voltage class is shown in Fig. 13.14 (275 kV), Fig. 13.15 (220 kV) and Fig. 13.16 (330 kV). The transmission losses were calculated on the objective lines and associated lines which would be influenced by the voltage differences between three voltages of the project lines. Specifically, they are the lines enclosed by Barka P.S., Barka S.S., Khuwair S.S., Ghubrah S.S. and Rusail P.S.

The required capacity of static condensers was calculated on the whole power system.

As a result of these comparison studies, almost no difference was recognized between 275 kV and 220 kV, while 220 kV looked slightly more advantageous. On the other hand 275 kV is advantageous as compared with 330 kV. For the following reasons, it is decided to adopt 275 kV.

- The voltage difference is small between 220 kV and existing 132 kV, and it is not suitable to adopt 220 kV.

- To obtain the current carrying capacity of 740 MW equivalent to the output of Barka P.S., 220 kV line has to use large sized conductors compared with other voltages and construction cost will be higher accordingly.

- 275 kV line will be able to have a enough function as a primary transmission line for about 20 years after its construction, based on a long term forecast of the power system.

- Although 330 kV is superior to 275 kV in that it has less transmission losses and is advantageous to maintain the system voltage, the construction of lines and associated substations are costly.

- 330 kV line and its associated apparatuses seem to have excessively large capacity against the demand scale of the power system (about 2,000 MW at the peak hours in 1995).

Table 13.4 Comparison of Transmission Voltage Classes

Transmission Voltages / Cost & Losses	220 kV	275 kV	330 kV
Construction Cost (Thousand RO)			
Substations	13,728	15,664	17,452
Transmission lines	9,053	7,379	7,880
Transmission losses			
Peak power losses (kW)	6,465	6,399	5,142
Annual energy losses (10^6 kWh)	21.35	21.13	16.98
Static condenser (MVA)	440	415	385
Annual cost (Thousand RO)			
Substations	1,728	1,972	2,197
Transmission lines	994	810	865
Power losses	230	227	183
Energy losses	204	202	162
Total	3,156	3,211	3,407

Note: (1) Annual cost factor

a. 0.1259 for substation
b. 0.1098 for transmission line

(2) Cost for power loss and energy loss

a. 35.55 RO/kW/year, which is annual fixed cost of Barka P.S.
b. 9.54 Baizas/kWh, which is variable (fuel) cost of Barka P.S.

(3) Annual energy loss

The following equations are commonly used to establish annual energy loss.
Ploss = 8,760 (hours) x Pm x Lr (kWh)

Where

Ploss : annual energy Loss (kWh)
Pm : peak power loss (kW)
Lr : ratio of average power loss to peak power loss, obtained from an experimental equation of Buller-Woodrow;
$Lr = 0.3f + 0.7f^2$, where f = 0.55 annual load factor of MEW network.

(3) Determination of Tie-Transformer Capacity

The tie-transformers (275/132 kV) to be installed in Barka S.S. and Khuwair S.S. are standardized in unit capacity and the same unit capacity is adopted in both substations. The unit capacities studied here are 125 MVA, 150 MVA, 200 MVA and 250 MVA.

As a result of power flow calculations for respective transformer capacity at the peak load hours in 1991 and 1995, 250 MVA has been selected as the standard unit capacity which will satisfy the following conditions:

- The number of units for Barka S.S. is 2 banks and for Khuwair S.S. 3 banks.

- Even if one bank is out of service, the other transformer(s) will not be overloaded.

- Even if one of the associated transmission lines is out of service, the transformers will not be overloaded.

The power flows on the tie-transformers (in case of 250 MVA) are shown in Fig. 13.9 (1), (2). Table 13.5 gives the operating condition of the tie-transformers and their power flow in MVA. The calculation shows that the utilization rate of the tie-transformers under the normal operation is 65% for Barka S.S. and 64% for Khuwair S.S. in 1991 power flow conditions.

And in 1995 the rate becomes 55% for Barka S.S. and 70% for Khuwair S.S.

If a bank of the tie-transformers is out of service, the power flow of the remaining transformer(s) will not exceed its rated capacity in the both years.

Table 13.5 Power Flow of Tie-Transformers

(MVA)

Condition of Operation \ Year / S.S.	1991 Barka 250MVAx2	1991 Khuwair 250MVAx3	1995 Barka 250MVAx2	1995 Khuwair 250MVAx3
Normal	324	476	275	527
Barka S.S. Tr 2 banks → 1 bank (250 MVA)	248	545	207	586
Khuwair S.S. Tr 3 banks → 2 banks (500 MVA)	369	429	321	475
Barka S.S. - Khuwair S.S. 2 lines → 1 line	372	417	325	463

(4) Stability

Fig. 13.10 through Fig. 13.16 show the swing curves of generators as a result of power system stability calculation.

1) System in 1991

Fig. 13.10 shows the case of applying the disturbance to the closest terminal of Barka P.S. and opening one of the two lines between Barka P.S. and Barka S.S. under the power flow condition of 1991.

Fig. 13.11 shows the case of applying the disturbance to the closest terminal of Barka S.S. and opening one of the two lines between Barka S.S. and Khuwair S.S.

In both cases, the generators are stable and their perturbations caused by the disturbance are converging in 3.0 to 4.0 seconds.

2) System in 1995

Fig. 13.12 shows the case of applying the disturbance to the closest terminal of Barka P.S. and opening one of the two lines between Barka P.S. and Barka S.S.

Fig. 13.13 shows the case of applying the disturbance to the closest terminal of Barka S.S. and opening one of the two lines between Barka S.S. and Khuwair S.S.

In both cases, the generators are found stable and their perturbation caused by the disturbance is converging in 2.0 to 3.0 seconds.

The perturbation in 1995 system is less in its magnitude compared with the 1991 system, though the same disturbance is applied to the line. This is attributable to the fact that the 1991 system has generators for Batinah area in Copper Mine and Sohar, but the 1995 system has, in addition, new generators in Khabourah. With this new power station in Khabourah, the heavily loaded lines of the 132 kV are relieved, and the phase differences between generators are made smaller than that of 1991, resulting in a stable operation of the generators.

3) Fault clearing time

The generator swing curves when the fault clear time is 0.10, 0.15 and 0.30 seconds under the same disturbance conditions are shown in Figs. 13.12, 13.14 and 13.15. The distrubance was applied to the closest terminal of Barka P.S. under the power flow conditions (Fig. 13.6) of 1991, with one line between Barka P.S. and Barka S.S. opened.

As the fault clearing time increases, naturally the perturbations of the generators become larger, although it is still stable even in case of 0.3 seconds and the perturbations are converging in 4.5 to 4.0 seconds after the disturbance occurred.

If the main protective relay of the transmission line operates normally, the fault will be cleared within 0.1 seconds, and even if the teleprotection fails, the fault wil be cleared within approximately 0.3 seconds by the operation of the back-up protective relay.

4) Voltage characteristics of load

The generator swing curves are shown in Figs. 13.14 and 13.16 when the voltage characteristic of a load is of a constant-impedance (simulates lamp load) and a constant-current (simulates motor load) under the same disturbance conditions, respectively.

The disturbance was applied to the closest terminal of Barka P.S. under the power flow conditions of 1991 (Fig. 13.6), and one line between Barka P.S. and Barka S.S. was opened. As a result of the calculations, there is almost no difference perceived in the swing curves due to load characteristics. For the MEW system, there is no instability factor because the transmission distance is short and the phase differences among the generators are very small. For this reason, the impact of a slight difference in the load characteristic on the generator swing curves can be almost ignored.

The static condenser for the system voltage correction described in (1) is also required in order to improve the stability.

(5) Short-circuit current

The short-circuit current was calculated based on the system configuration of 1995. Fig. 13.17 shows the short-curcuit capacity of the busses and current flow in the lines. The maximum short-curcuit current for each voltage class is as follows.

275 kV bus (Barka P.S.)	6,097 MVA (12.8 kA)
132 kV bus (Rusail P.S.)	5,635 MVA (24.6 kA)
33 kV bus (Khuwair S.S.)	1,689 MVA (29.5 kA)

(6) Location of new power station

Two cases of power flow study were carried out, assuming a location in the neighborhood of Khabourah S.S. or Khuwair S.S. as the possible sites to develop a new power station after construction of Barka P.S. Fig. 13.6 and Fig. 13.18 show the power flow with a new power station in Khabourah and Khuwair, respectively.

The power flow shown in Fig. 13.6 is as described in preceding items (1), 4) and there will be no overloaded line as far as the network is operating normally.

On the other hand, in the case of Fig. 13.18, the power flow between Barka S.S. and Musanna S.S. is 436 MW, which will exceed its permisible limit (370 MW/2 lines). Therefore, a transmission line must be additionally installed in this section.

Table 13.6 shows the comparison of transmission losses between these two candidate places. The Khuwair case has an extremely large losses on both of the active power and reactive power. When the active power losses are compared on annual cost basis, the difference amounts to as large a sum as about 500 thousand RO.

All these hint that a place in Khabourah is extremely advantageous.

In Fig. 13.18, it is noted that Khabourah - Musanna and Khabourah - Sohar lines are heavily loaded. This is because the output of Khaboura P.S. was set at 480 MW and part of the power is sent to the Capital area. In planning the Batinah coast power station, the following points should be taken into consideration:

- An output of the power station should be so determined that the supply and demand balance can be kept within the Batinah coast.

- Since the Batinah coast has a vast area and the load center is dispersed, an appropriate location of the power station to meet the load distribution should be selected.

Table 13.6 Comparison of Power Development Sites

Losses & Cost \ Sites	Khabourah	Khuwair
Transmission Power losses		
Active Power (MW)	30.99	38.74
Reactive Power (MVar)	498.52	587.02
Annual energy losses		
Active Power (10^6 kWh)	102.35	127.94
Annual cost (Thousand RO)		
Power losses	1,071	1,339
Energy losses	976	1,221
Total	2,047	2,560

Note: Cost for power losses and energy losses are same as Table 13.4

13.4 FREQUENCY DROP AND SYSTEM OPERATION

The maximum unit capacity of generators employed at Barka P.S. is 80 MW. In this section, frequency drop and system operation method when the generator is out of service are considered.

13.4.1 Frequency Drop

Frequency change of power system is formulated as follows.

$$\Delta F = \frac{-1}{K} \times \frac{\Delta P}{P} \times 100 \text{ (Hz)}$$

where:

ΔF :	Frequency change (Hz)
ΔP :	Change of system load or output of generator (MW)
P :	Total load of power system (MW)
K :	System constant (=KG+KL) (%MW/0.1 Hz) (i.e. regulating energy)
KG:	Frequency characteristics of generators (%MW/0.1 Hz)
KL:	Frequency characteristics of loads (%MW/0.1 Hz)

The system constant K is the sum of KG and KL. Since KG is determined by the speed droop of the generator, it differs depending on how many generators are operating in governor-free, and KL differs depending on the characteristics of the loads.

According to the statistical survey in some power systems, the value of K is within the range of 0.85 - 1.40 %MW/0.1 Hz, and it is mostly centered at about 1.0 %MW/0.1 Hz. For this calculation, an average value of 1.0 %MW/0.1 Hz was used though its an inherent value of the system obtained by actual measurements should be used.

(1) 80 MW unit

It is predicted that the peak load in the summer of 1988 when the 80 MW gas turbine generator goes into operation will be 853 MW, while the lowest load in the winter of 1989 will be 161 MW. With such a scale of demand, if the generator output at the time of unit drop-out is 80 MW and 40 MW, the frequency drops will be calculated as follows:

Drop-out capacity of generator (MW)	System load (MW)		Frequency drop (Hz)	Frequency of System (Hz)
80 (100%)	Peak	853	- 0.93	49.07
40 (50%)	Off-peak	161	- 2.48	47.52

Note: Results of the frequency drop calculation from 1988 to 1993 are shown in ANNEX 6.

(2) Allowable limit of frequency drop

Allowable range of frequency change for operating thermal machines is limited by the resonance frequency of rotating blades of turbines.

Lower limit of frequency to allow continuous operation of thermal machine is 48.5 Hz (-1.5 Hz).

As less than 48.5 Hz, allowable operating time is shorter as the frequency is close to the resonance frequency of turbine.

A turbine with capacity of 125 MW or less can be operated for a few minutes at the frequency of 47.5 Hz, with some difference depending on capacity of a turbine. At frequency of 47.5 Hz, turbines should be tripped from the system instantaneously or within 30 seconds.

13.4.2 System operation

To operate a thermal machine within the allowable range of frequency, the system should be operated in accordance with procedures described below. However, a 80 MW generator can be normally operated under the rated output during peak-load hours in view of the frequency variation.

(1) Generator output during off-peak times

The lower limit of frequency at which the generator can be continuously operated is 48.5 Hz (-1.5 Hz) for the 50 Hz generators. In order to maintain the frequency after the unit drop-out higher than 48.5 Hz, the output of the generator in operation must be controlled to less than 15% of the system load (in case of K=1.0 %MW/0.1 Hz).

ANNEX 6 shows an example of combination of generators in operation which meets both power and water demands in summer peak hours and in winter off-peak hours, respectively. Frequency deviation is being kept within an allowable limit by this arrangement.

(2) Load shedding

If the frequency drop cannot be maintained within the allowable limit by mean of reducing the output of each generator during off-peak hours, partial load shedding should be done by the frequency relays.

The stages of load shedding and presetting examples of frequency relays are shown below for reference.

Presetting		Shedding loads
First stage	49.0 Hz	Load-A *
Second stage	48.5 Hz	Load-B
Third stage	48.0 Hz	Load-C

* Load A - C : Feeders of the substations for load shedding according to the pre-set priority.

The above items (1) and (2) are an engineering practice to prevent an entire black-out of a small system which might be caused by frequency drop at the time of generator drop-out, and is essential to maintain a power system in safe conditions. On the other hand, the above system operation is not required when the system become large and is not seriously affected by generator drop-out.

13.5 CONCLUSION AND RECOMMENDATIONS

Summarized in the following are the results of the system analysis and recommendations which may be used for future system planning.

(1) Selection of transmission voltage

As for the voltage to be introduced when the Barka P.S. is constructed, 275 kV was selected.

(2) Tie-transformer capacity

The unit capacity of the 275/132 kV tie-transformer to connect the existing 132 kV network and a new 275 kV network was determined to be 250 MVA.

(3) Stability

The 740 MW power generated at Barka P.S. can be transferred stably to the load center through the new 275 kV lines and the existing 132 kV lines. All generators can operate stably against the disturbance to the system.

(4) Short-circuit current

The short-circuit current is not at such a level as to pose a problem in the 275 kV and 132 kV networks from the viewpoint of the circuit breaker duties. In the 33 kV network, it is at a relatively high level in the substations in the Capital area.

(5) Countermeasures against overloading of transmission line

In 1988 the 275 KV transmission lines will be introduced for the power system of MEW. However, the 132 kV lines will still occupy a major portion of the network.

The current carrying capacity of the 132 kV line is given as 185 MW/line (Table 11.1). At the peak demand in 1995, the load of each substation in the Capital area will exceed an order of 100 MW. The power flow from Khuwair S.S. to Wadi Adai S.S. is about 600 MW and the power is transferred through 4 lines of 132 KV. If one of 4 lines is out of service, the remaining lines will be overloaded. As a method to solve the overloading problem, the following plans have been conceived:

(a) Addition of the 132 KV lines

(b) The extension of the 275 kV lines from Khuwair S.S. further to Wadi Adai S.S.

(c). Construction of new power station in the vicinity of Wadi Adai S.S.

All of these plans will be subject to environmental restrictions. However, the effective method from the viewpoint of the power system is Plan (C).

(6) Machine Constant to be specified (Generators, Transformers)

Since most of the demand at the summer time in this system is for the air-conditioners, the load power factor will be low and the reactive power consumption will be large. For this reason, the power supply equipment (generators, transmission lines, transformers) should be specified so as to meet the characteristics of the system load.

A generator, for instance, must be designed to have a low power factor and can supply a great amount of reactive power. At the same time, reactive power consumed in the lines and the transformers should be decreased.

Accordingly, the power factor of the generators installed in this system is 0.8. On the other hand, the impedance voltages of the 132/33 kV transformers adopted by MEW seem to be very high at about 18%. This means that the consumption of reactive power and the voltage drop of the system increase, although there is a merit that the short-circuit current of the 33 kV network can be limited for a certain level. These advantages and disadvantages must be taken into consideration when the impedance voltage of the transformer is determined.

List of Figures

List of Figures (Concluded)

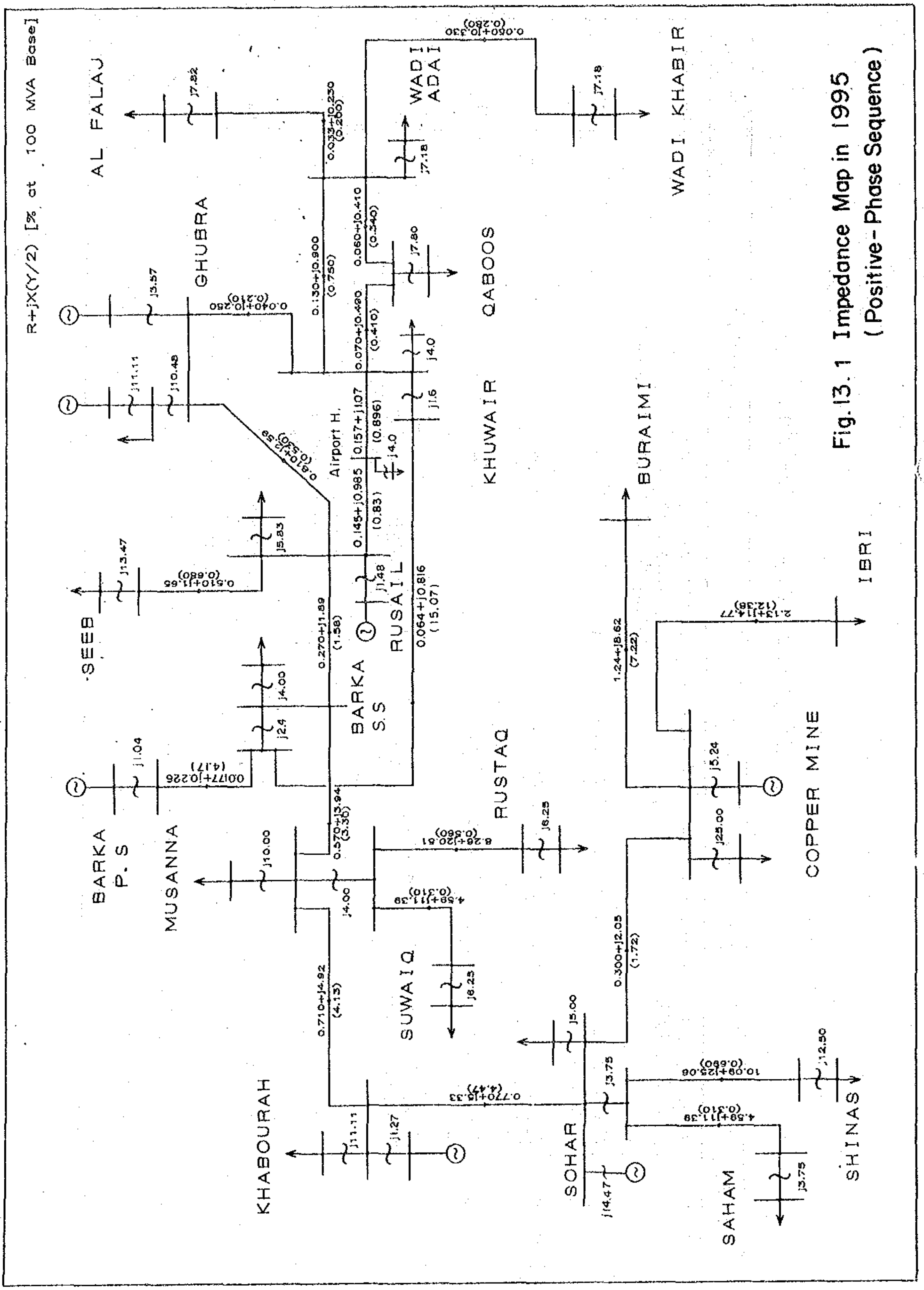


Fig. 13.1 Impedance Map in 1995 (Positive-Phase Sequence)

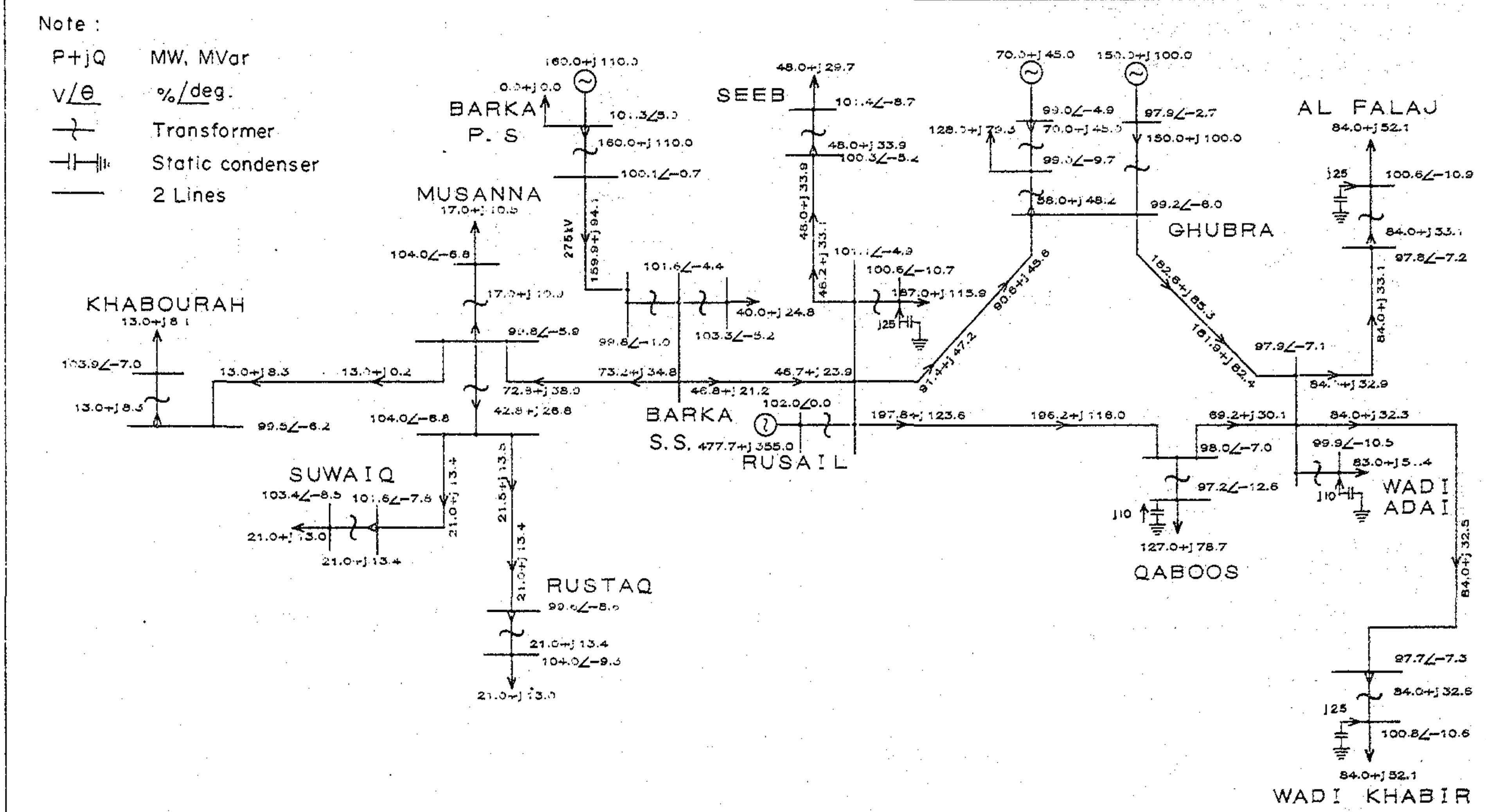


Fig. 13.2 Power Flow Diagram
(Peak hours in 1988)

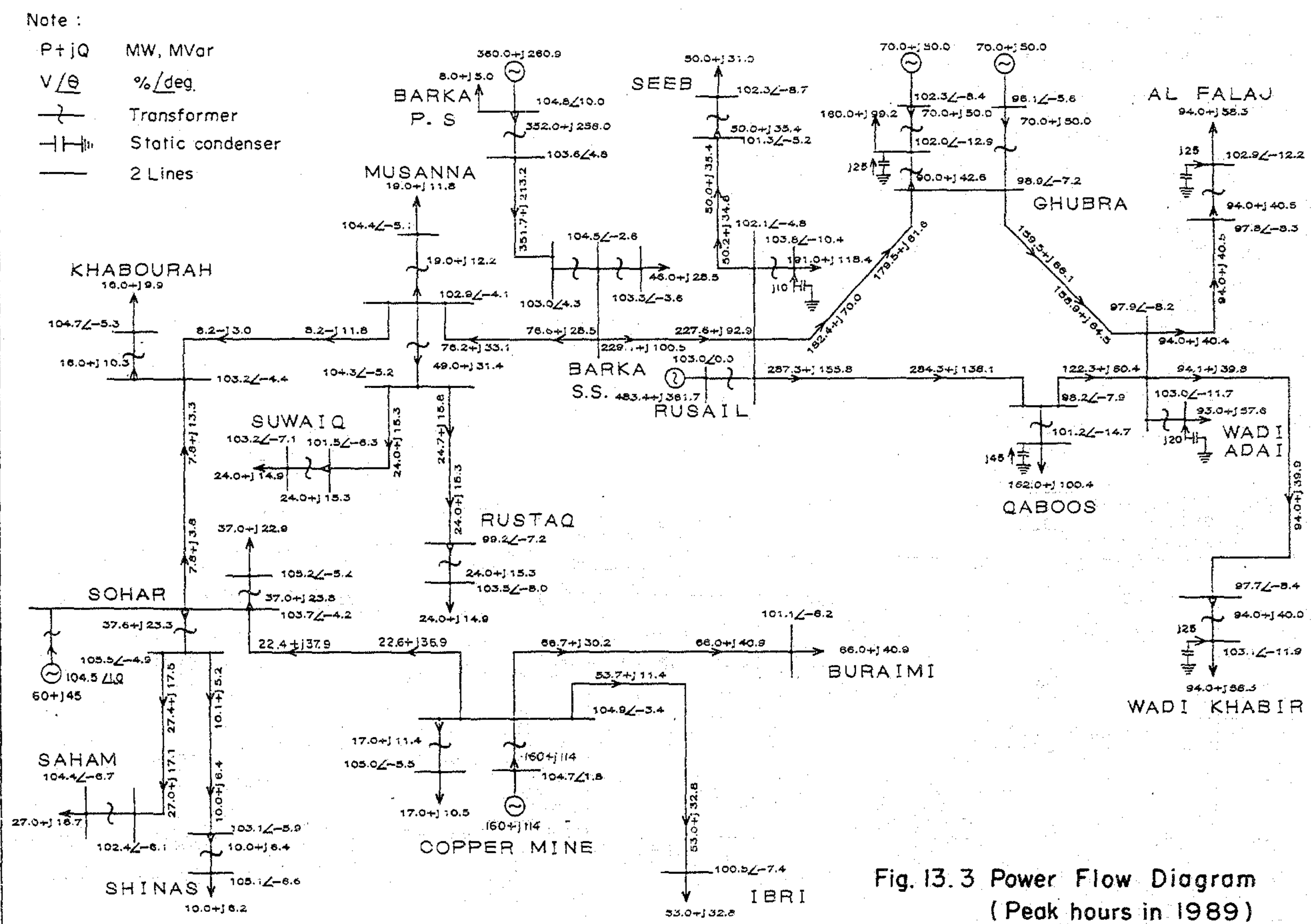


Fig. 13. 3 Power Flow Diagram
(Peak hours in 1989)
Barka S.S.~Khuwair Line is not constructed.

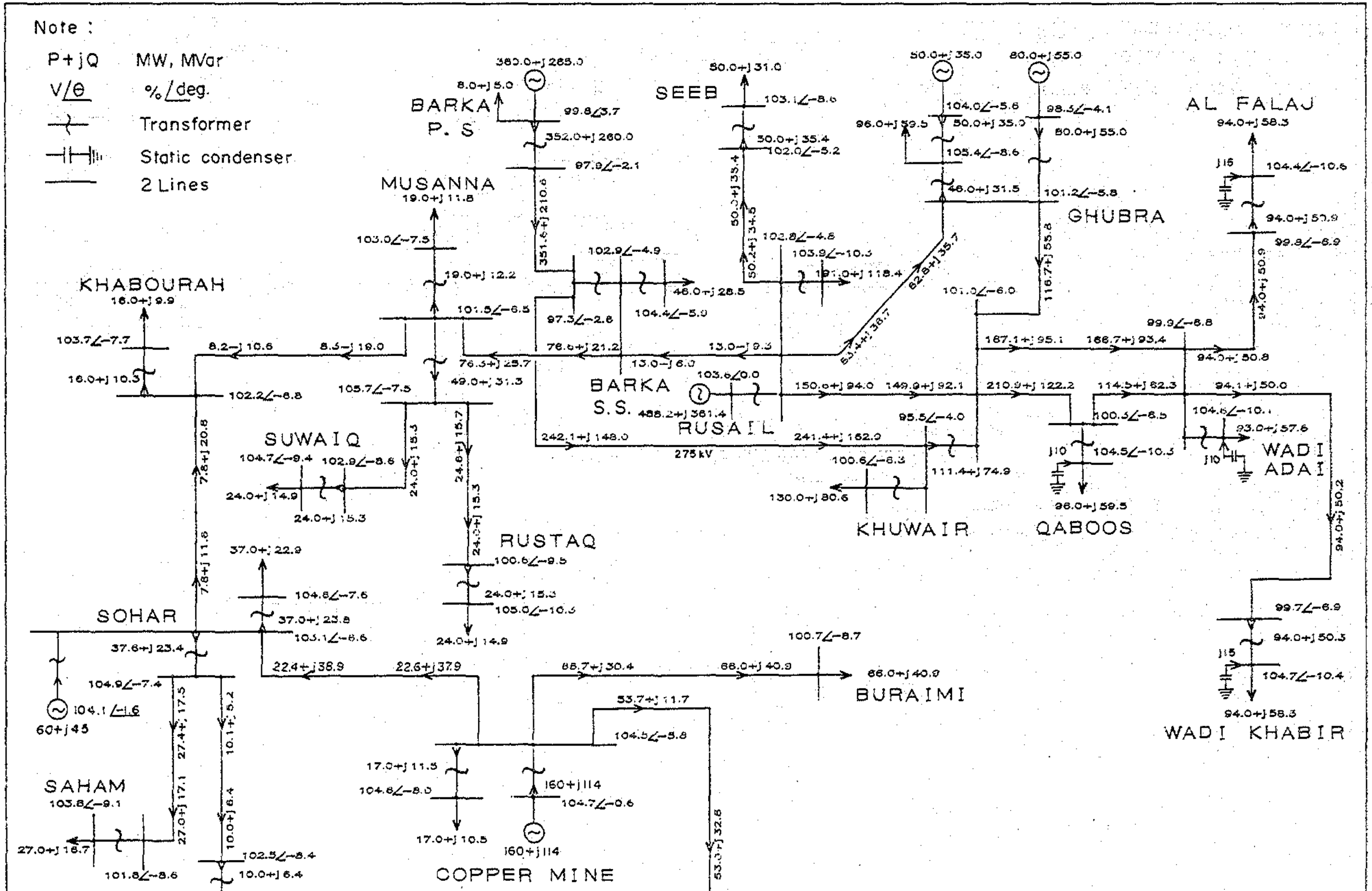


Fig. 13. 4 Power Flow Diagram
(Peak hours in 1989)
Barka S.S.~Khuwair Lines are constructed

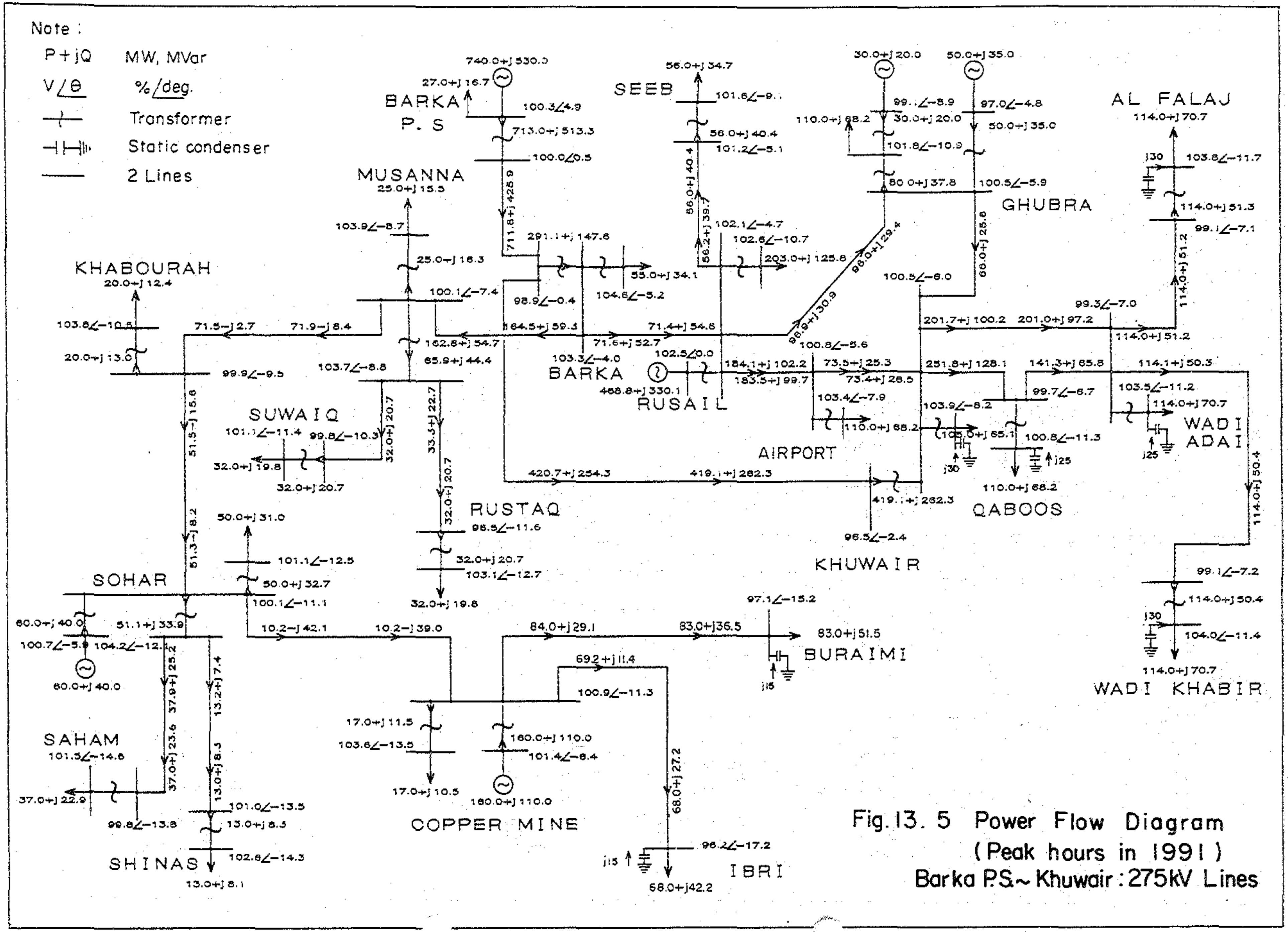


Fig. 13. 5 Power Flow Diagram
(Peak hours in 1991)
Barka P.S.~ Khuwair : 275kV Lines

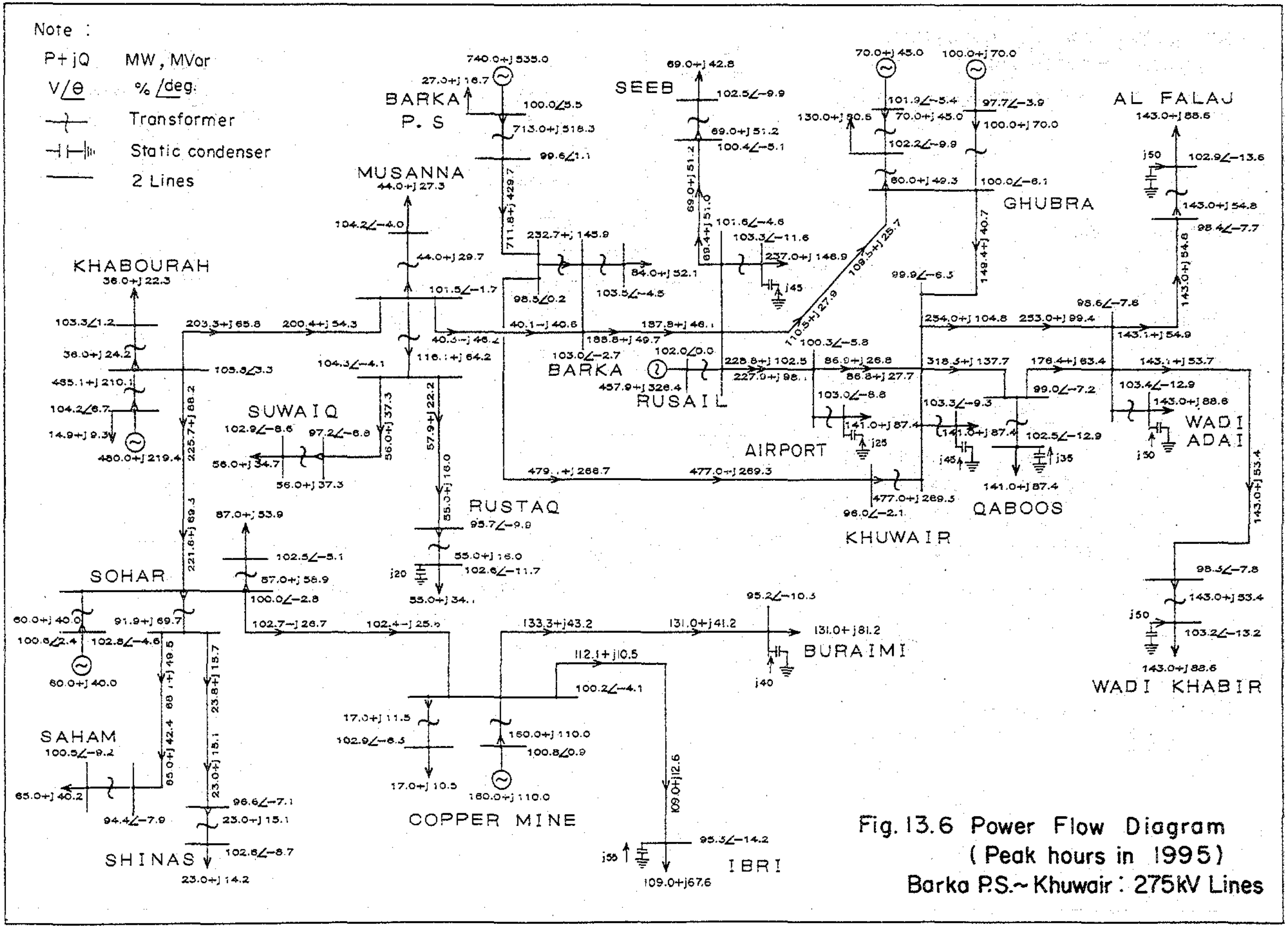


Fig. 13.6 Power Flow Diagram
(Peak hours in 1995)
Barka P.S.~ Khuwair : 275kV Lines

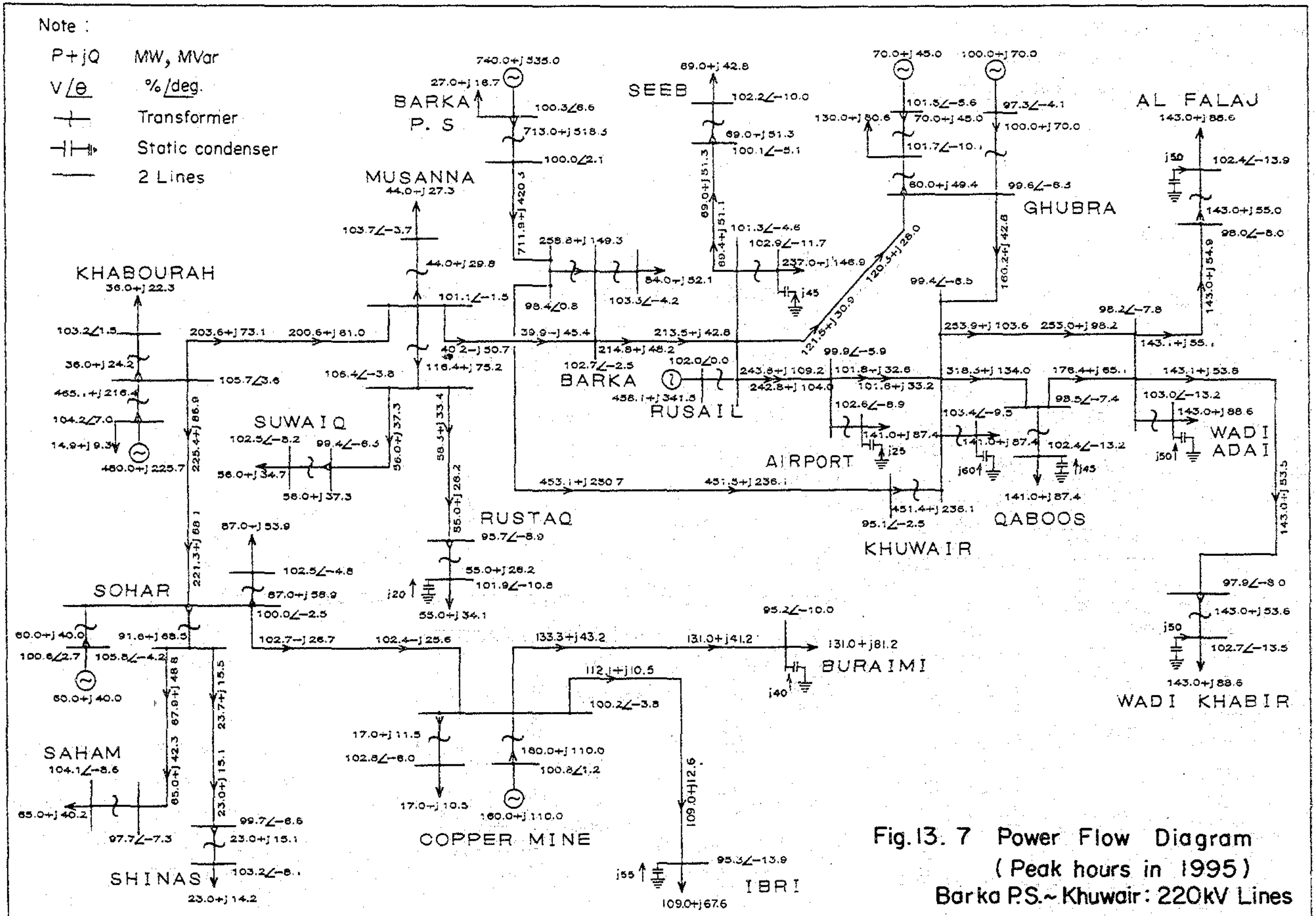


Fig. 13. 7 Power Flow Diagram
(Peak hours in 1995)
Barka P.S.~Khuwair: 220kV Lines

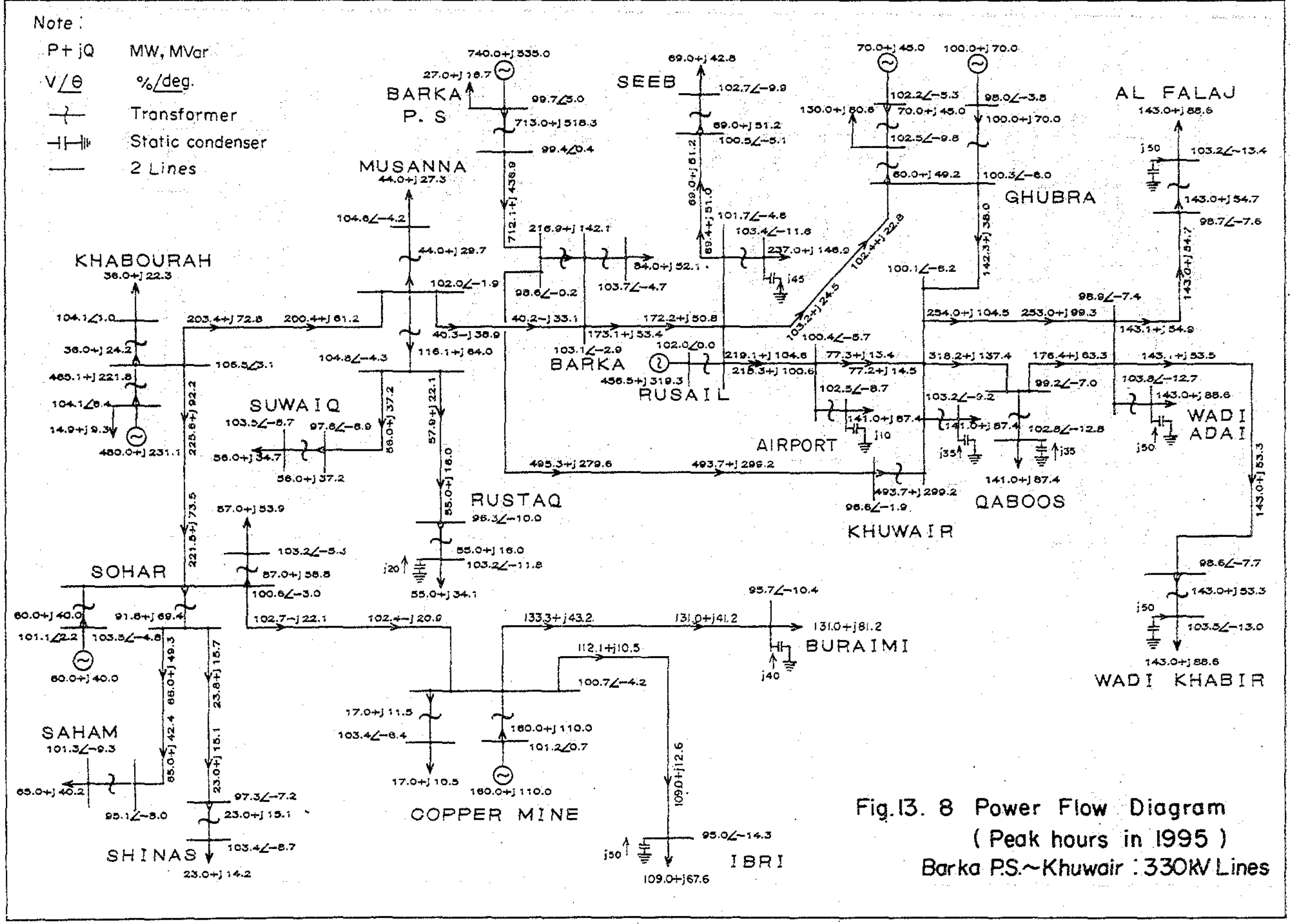


Fig.13. 8 Power Flow Diagram
(Peak hours in 1995)
Barka P.S.~Khuwair : 330kV Lines

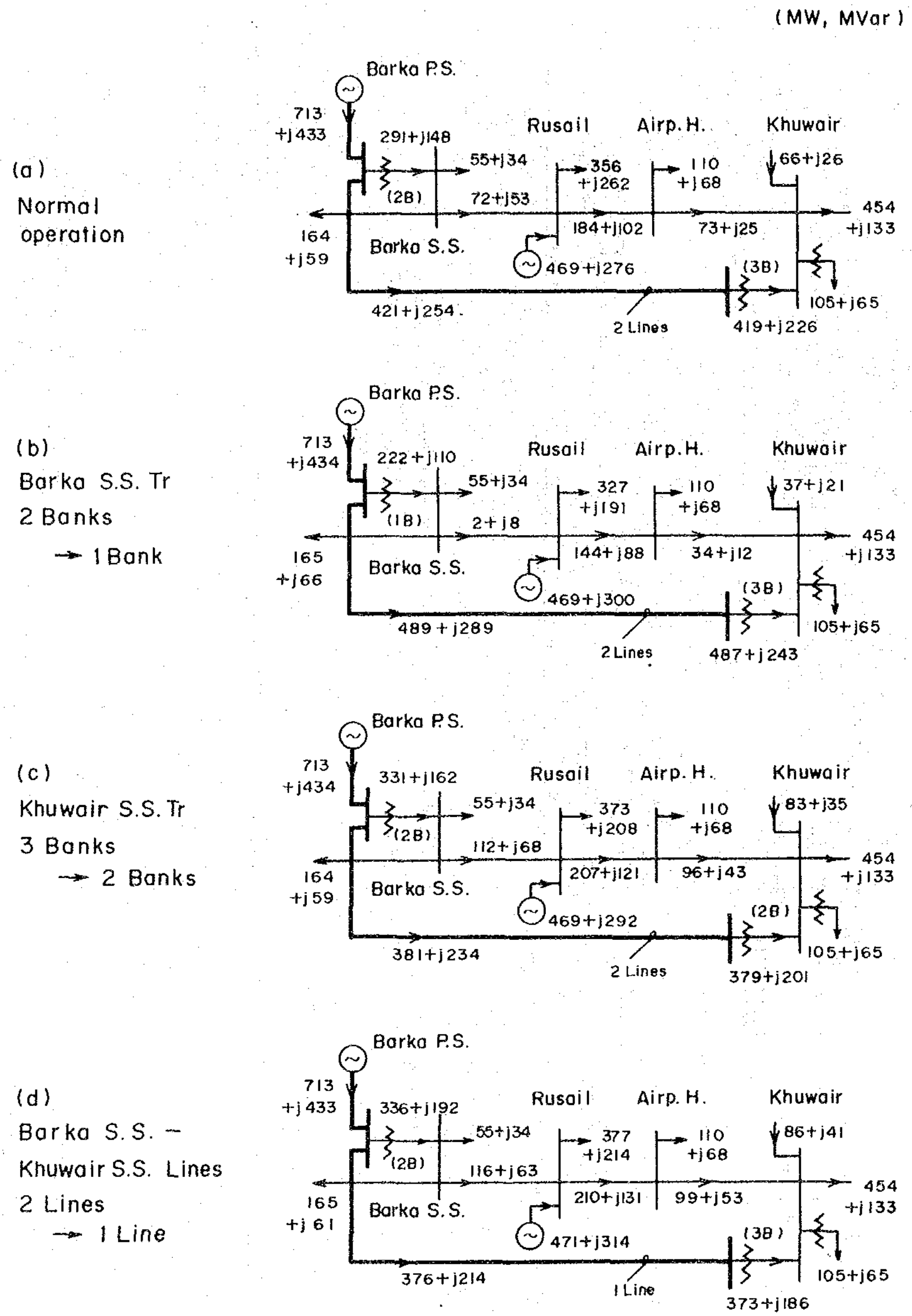


Fig. 13.9 (1) Power Flow Study for Tie-Transf. Capacity (1991)

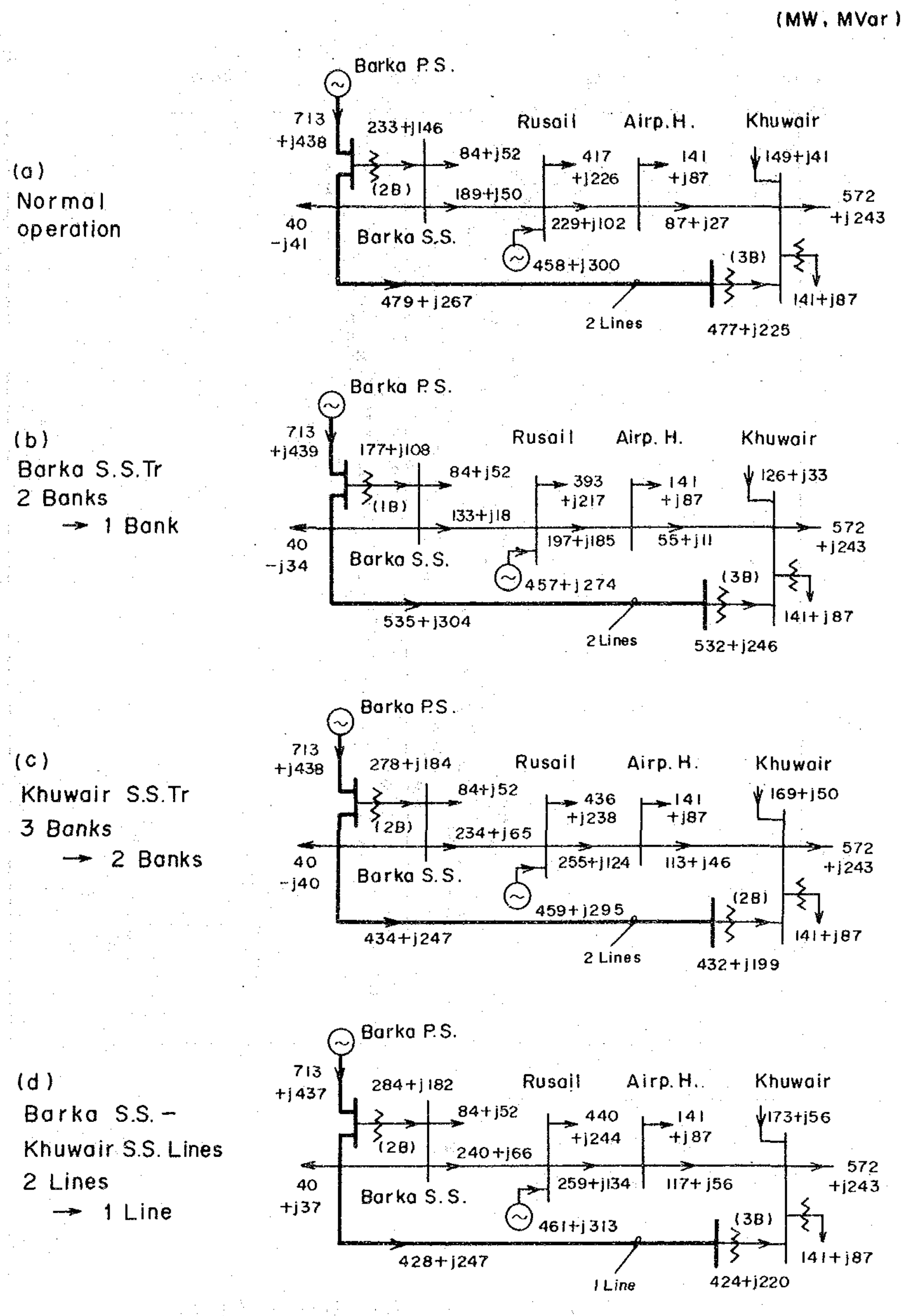
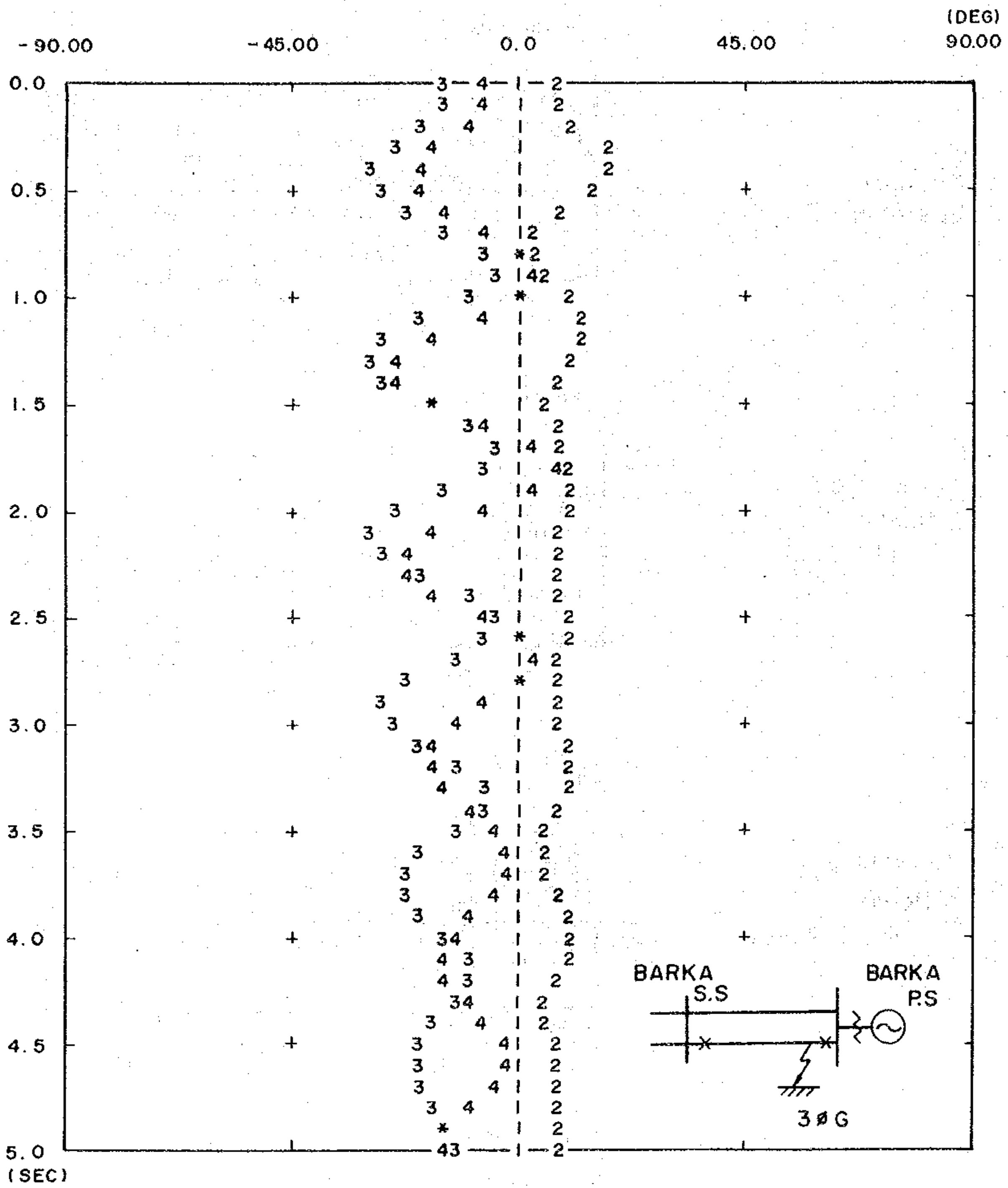


Fig. 13.9(2) Power Flow Study for Tie-Transf. Capacity (1995)



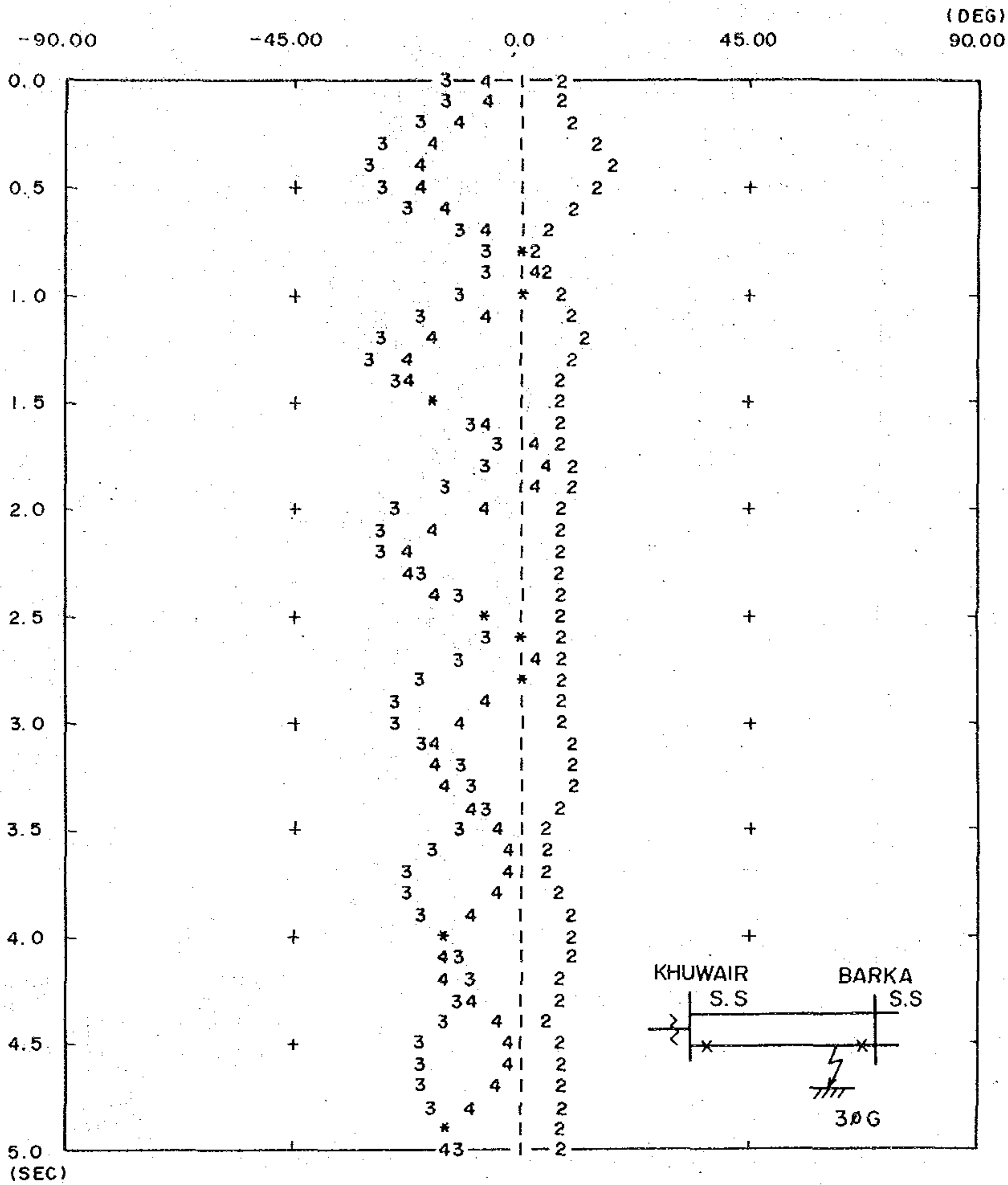
Symbol Generator:

1 = Rusail (Base) 2 = Barka 3 = Ghubra - 33kV

4 = Copper mine

Fig.13.10 Dynamic Stability Swing Curve after 3ø G - fault at Barka P.S (1991)

Fault clearing time : 0.1 sec.



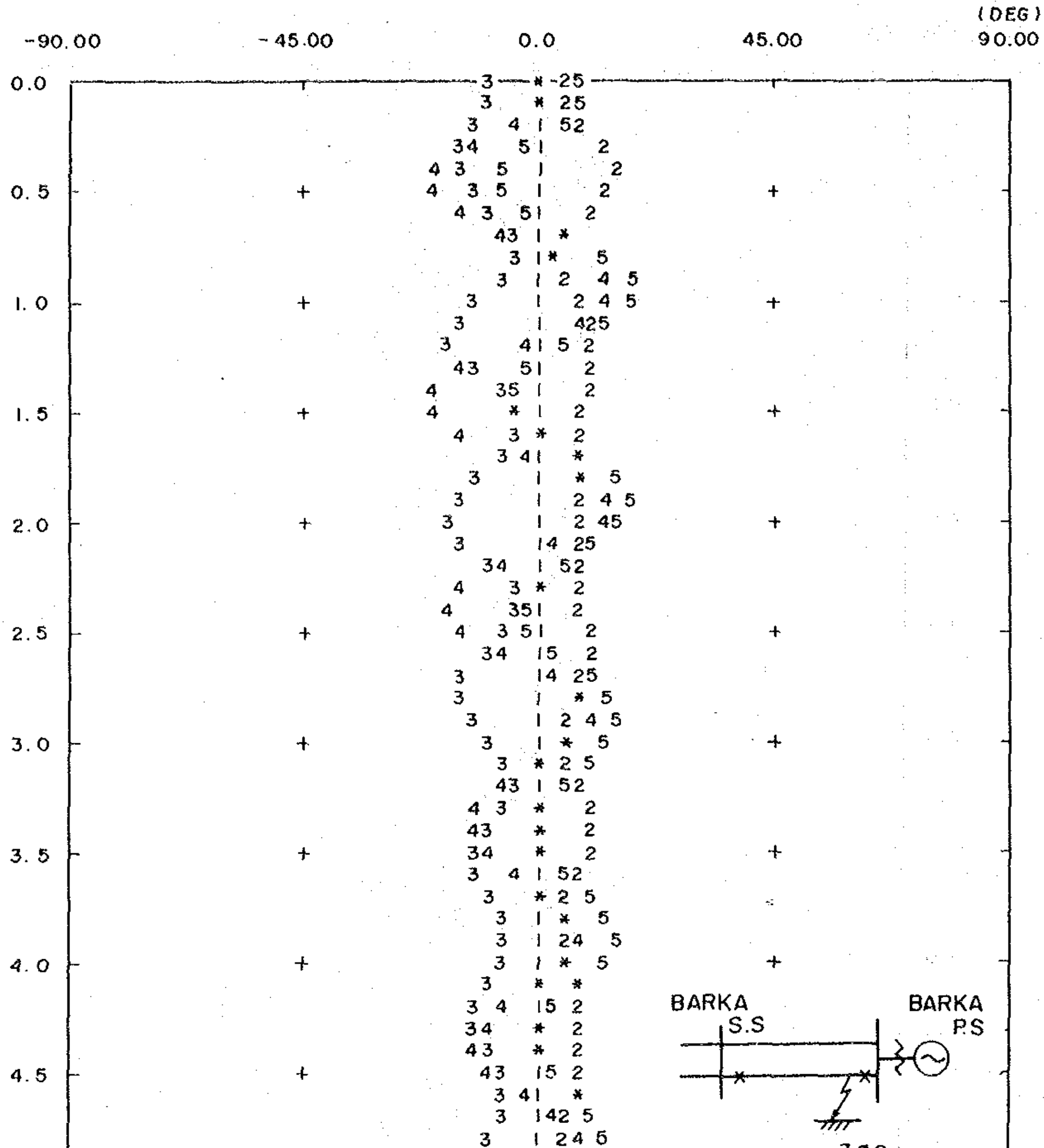
Symbol Generator :

1 = Rusail (Base) 2 = Barka 3 = Ghubra-33kV

4 = Copper mine

Fig. 13.11 Dynamic Stability Swing Curve after 3ØG - fault at Barka S.S (1991)

Fault clearing time : 0.1 sec.



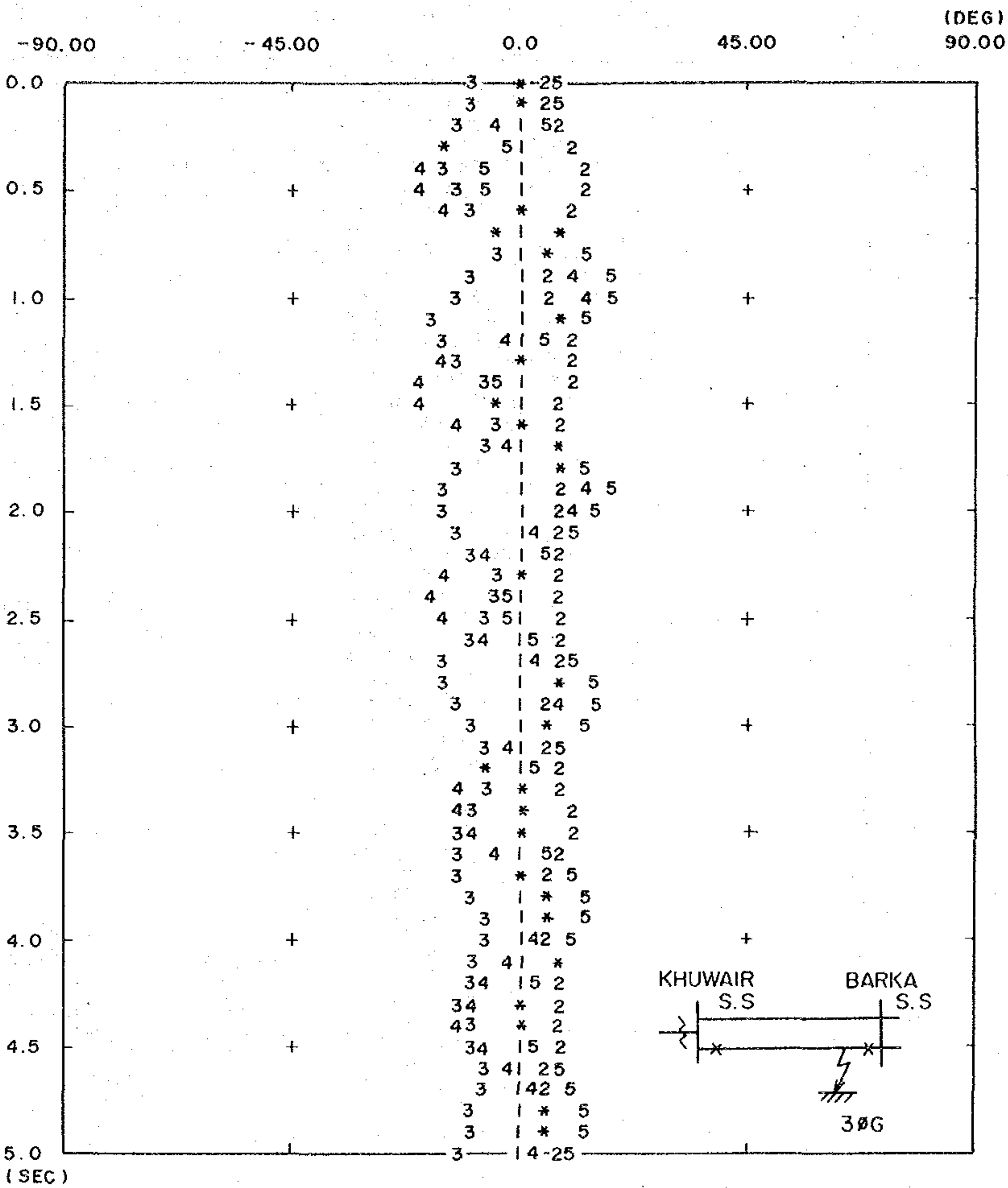
Symbol Generator :

1 = Rusail (Base)　　2 = Barka　　3 = Ghubra - 33 kV

4 = Copper mine　　5 = Khabourah

Fig. 13. 12 Dynamic Stability Swing Curve after 3ø G - fault at Barka P.S (1995)

Fault clearing time : 0.1 sec.



Symbol Generator :

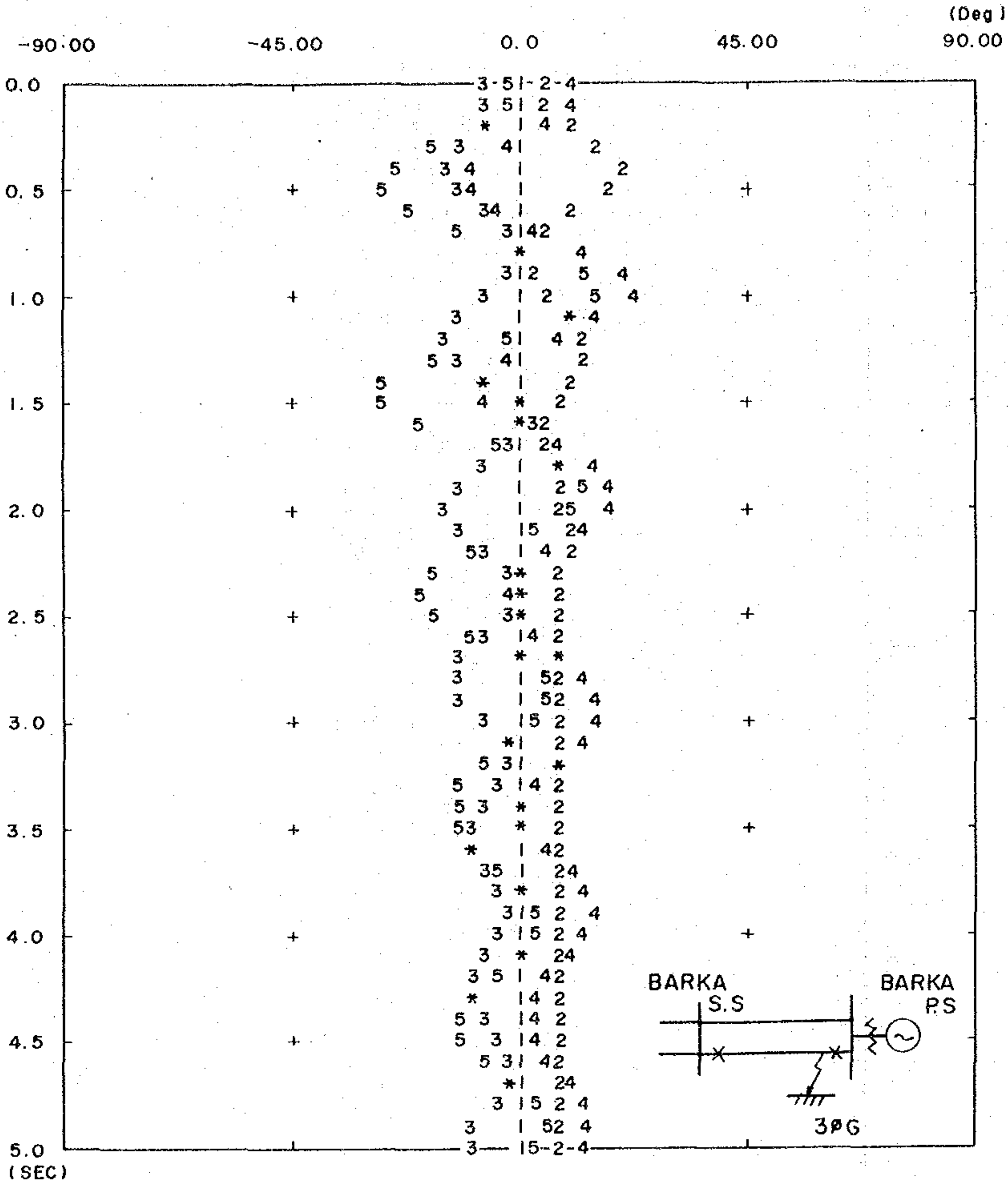
1 = Rusail (Base) 2 = Barka 3= Ghubra - 33kV

4 = Copper mine 5 = Khabourah

Fig. 13. 13 Dynamic Stability Swing Curve

after 3ØG - fault at Barka S.S (1995)

Fault clearing time : 0.1 sec.



Symbol Generator :

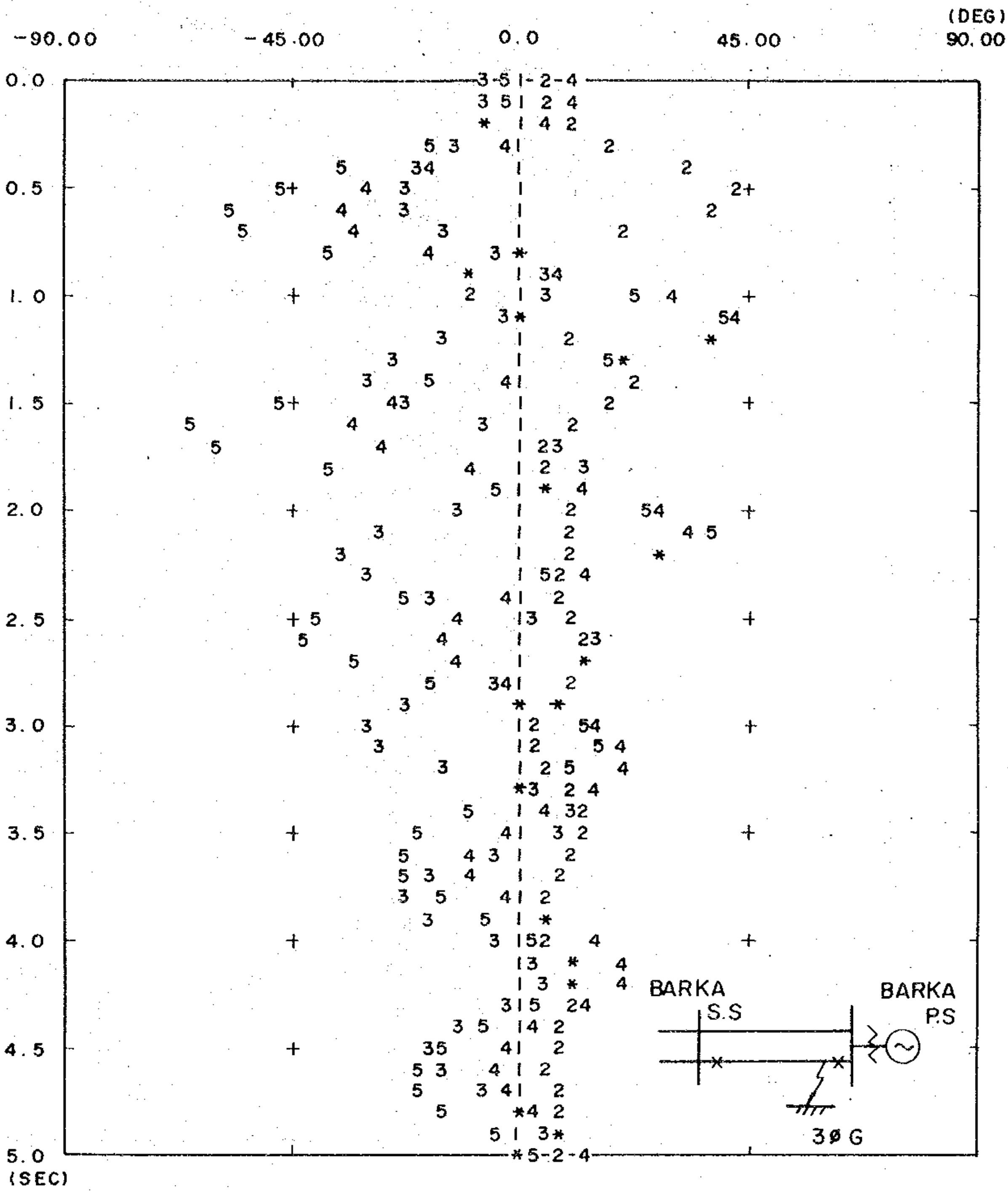
1 = Rusail (Base)　2 = Barka　3 = Ghubra - 33 kV

4 = Copper mine　5 = Khabourah

Fig. 13.14 Dynamic Stability Swing Curve after 3Ø G-fault at Barka P.S (1995)

Fault clearing time : 0.15 sec.

Load characteristics : Constant impedance (Ref. Fig. 13.16)



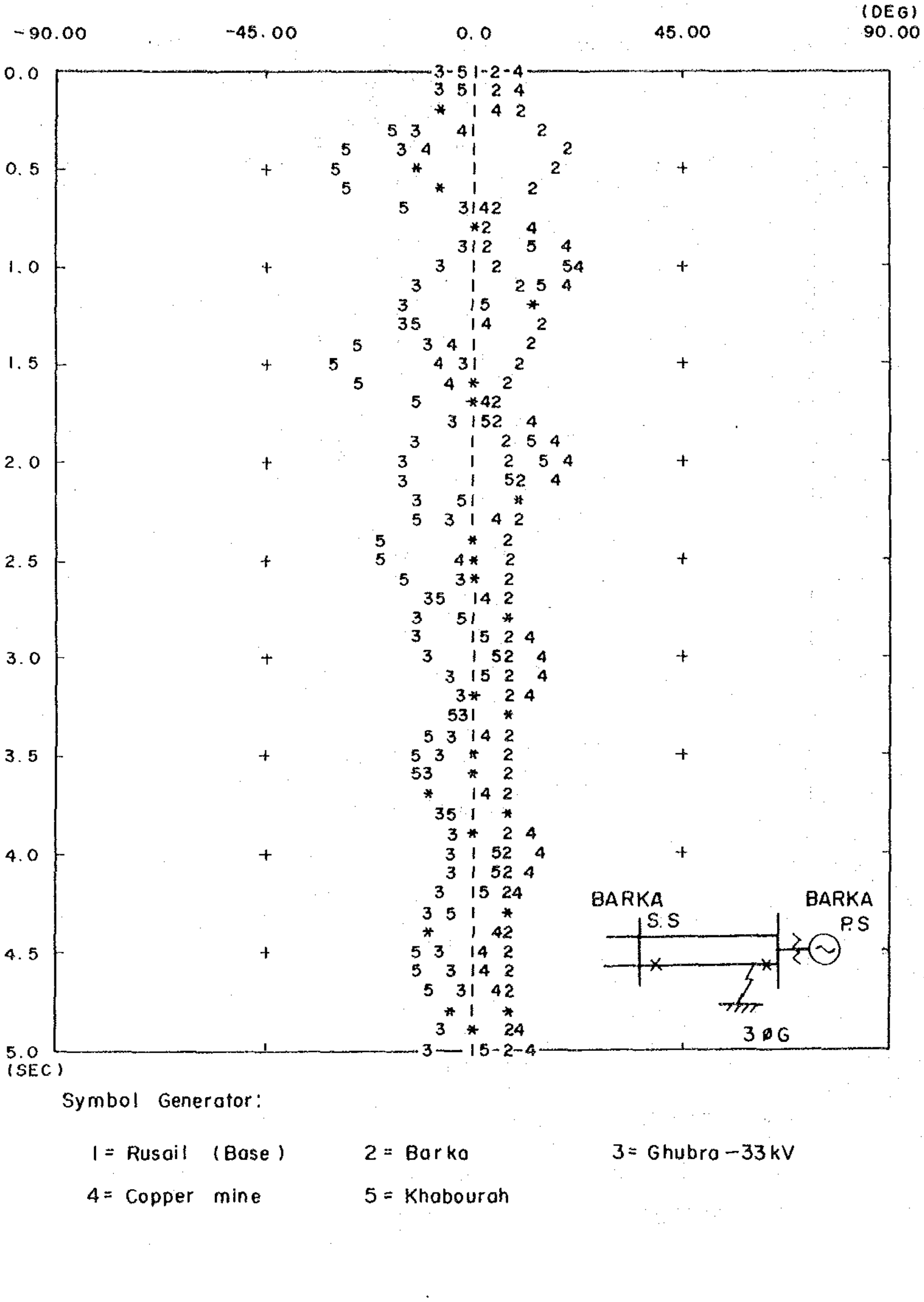
Symbol Generator :

1 = Rusail (Base) 2 = Barka 3 = Ghubra -33 kV

4 = Copper mine 5 = Khabourah

Fig. 13.15 Dynamic Stability Swing Curve after 3ø G-fault at Barka P.S (1995)

Fault clearing time : 0.3 sec.



Symbol Generator:

1 = Rusail (Base) 2 = Barka 3 = Ghubra – 33 kV

4 = Copper mine 5 = Khabourah

Fig. 13. 16 Dynamic Stability Swing Curve after 3øG – fault at Barka P.S (1995)

Fault clearing time : 0.15 sec.

Load characteristics : Constant current (Ref· Fig. 13 . 14)

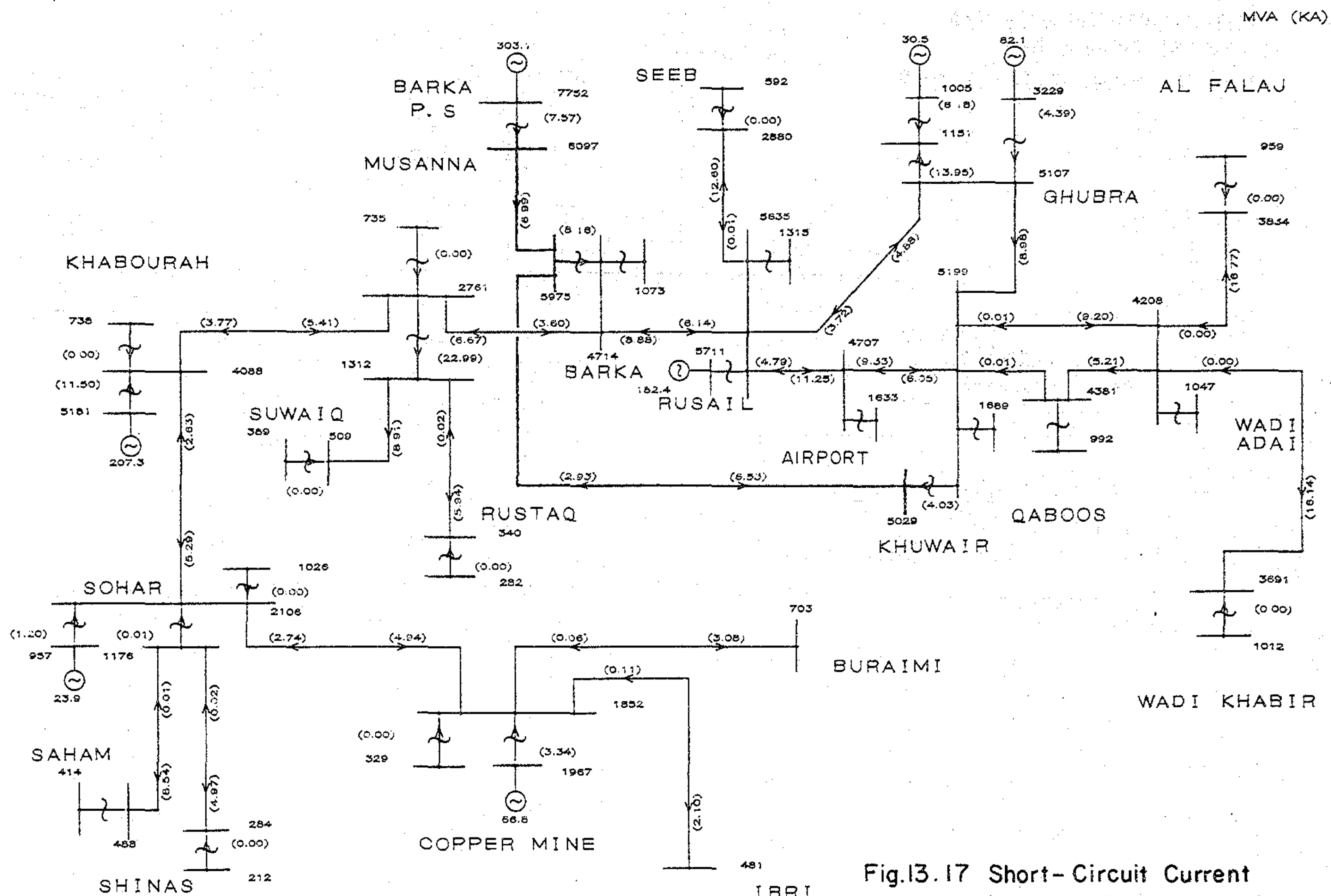


Fig.13.17 Short-Circuit Current (3-Phase Fault in 1995)

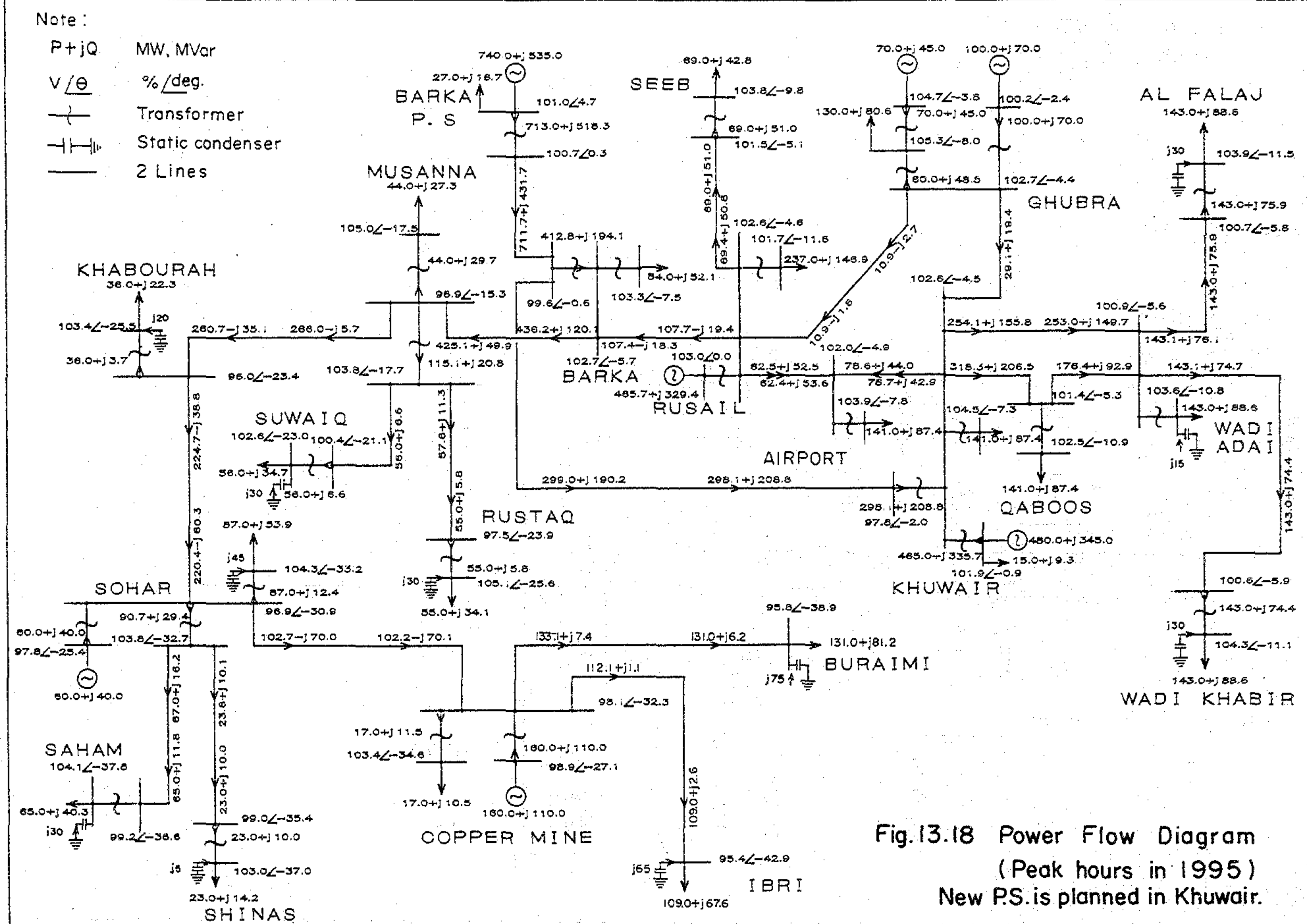


Fig. 13.18 Power Flow Diagram (Peak hours in 1995)
New P.S. is planned in Khuwair.

CHAPTER 14

BASIC PLAN OF WATER CONDUIT LINE

CHAPTER 14 BASIC PLAN OF WATER CONDUIT LINE

14.1 HOOKUP POINTS

14.1.1 Existing water distribution facility

The water distribution system of Capital Area covers the coastal area from Bustan area in the east to Seeb town in the west of which distance is approximate 50 km including Muscat and Mutrah, and also covers the inland area which is 15 - 20 km away from coast of Amirat and Medinat Al Nahda area and Rusail area. The water distribution system is expanding rapidly to meet the increase of water demand in town area and the development of west area, mainly in airport area.

The water source is mainly the sea water desalination plant in Ghubrah Station, and as the well water source, Wadi Aday/Amirat Well Field and Al Khawd Well Field are being developed. As well as the water distribution network, the water conduit network for gathering the well water to Ghubrah Station is under construction.

After completion of the planned conduit and distribution network now under construction, the product water of desalination plant are blended and adjusted with well water at Ghubrah Station and then distributed to the Capital Area.

Since present distribution capacity is approximately 136,000 m^3/d, it is necessary to increase remarkably the capacity of distribution network in order to distribute additional water of 216,000 m^3/d supplied from the new power and desalination complex plant to the Capital Area.

216,000 m^3/d breaks down into 180,000 m^3/d of product water of sea water desalination plant and 36,000 m^3/d of well water.

14.1.2 Forecast of the areas to distribute water

In order to decide the interface points of water conduit line with the distribution network, it is essential to analize each town developing plan and distribution of economic activities, and to forecast surely the demand distribution. According to the developing plan of Capital Area distribution network, not only the water demand of Capital Area at east of Ghubrah, but also the water demand of Capital Area at west of Ghubrah is expected to increase to a large extent, because many public facilities and residential complex are planned in these areas. Therefore, water distribution of 216,000 m^3/d supplied from the new plant is allocated as followings.

a. Reservoir at Ghubrah Station	;	108,000 m^3/d (50%)
b. Branch for Seeb Town	;	38,000 m^3/d (17.6%)
c. Branch for Airport Area	;	38,000 m^3/d (17.6%)
d. Branch for Azaiba, Ghalla and Bosher Areas	;	32,000 m^3/d (14.8%)
Total		216,000 m^3/d (100%)

14.1.3 Selection of hookup points

The hookup points between the water conduit line of new plant and the existing distribution system are the following 4 points:
(Refer to Fig. 14.1)

(1) At Ghubrah station

As to the eastern area, the major hookup point from the new plant to the existing distribution facility is to be the reservoir in Ghubrah Station. Accordingly, the water distributing capacity of Ghubrah Station is increased approximately twice from 136,000 m^3/d to 244,000 m^3/d, so the expansion of reservoir capacity and improvement of distribution facilities are also required in parallel with the new Barka project.

(2) Branch for Seeb town

The hookup point of conduit line from the new plant is to be at the branch valve, which will be installed at the nearest point to the existing distribution pipe for Seeb town.

Though the existing distribution facility has the capacity of approx. 9,000 m^3/d, the increase of distribution facility is required, and reservoir, etc. is to be so performed that large water flow rate from the new plant can be introduced.

(3) Branch for Airport area

The hook up point of conduit pipe from the new plant is to be at the branch valve, which will be installed at the nearest point to the water pipe for Seeb Airport Reservoir. As high level area is included in this branch line, it is recommended to install the distribution pump and the water reservoir near the branch point.

Though the existing distribution facility for Airport area has the capacity of approximately 2,500 m^3/d, the increase of distribution facility is required, and reservoir, etc. is to be so constructed that large water flow rate from the new plant can be introduced.

(4) Branch for Azaiba, Ghalla and Bosher

The branch valve is to be installed on the conduit line from the new plant, and be connected for these areas. Also, the distribution facilities of these areas are to be increased in the future. As high level area is included in this branch line, it is recommended to install the distribution pump and water reservoir near the branch point.

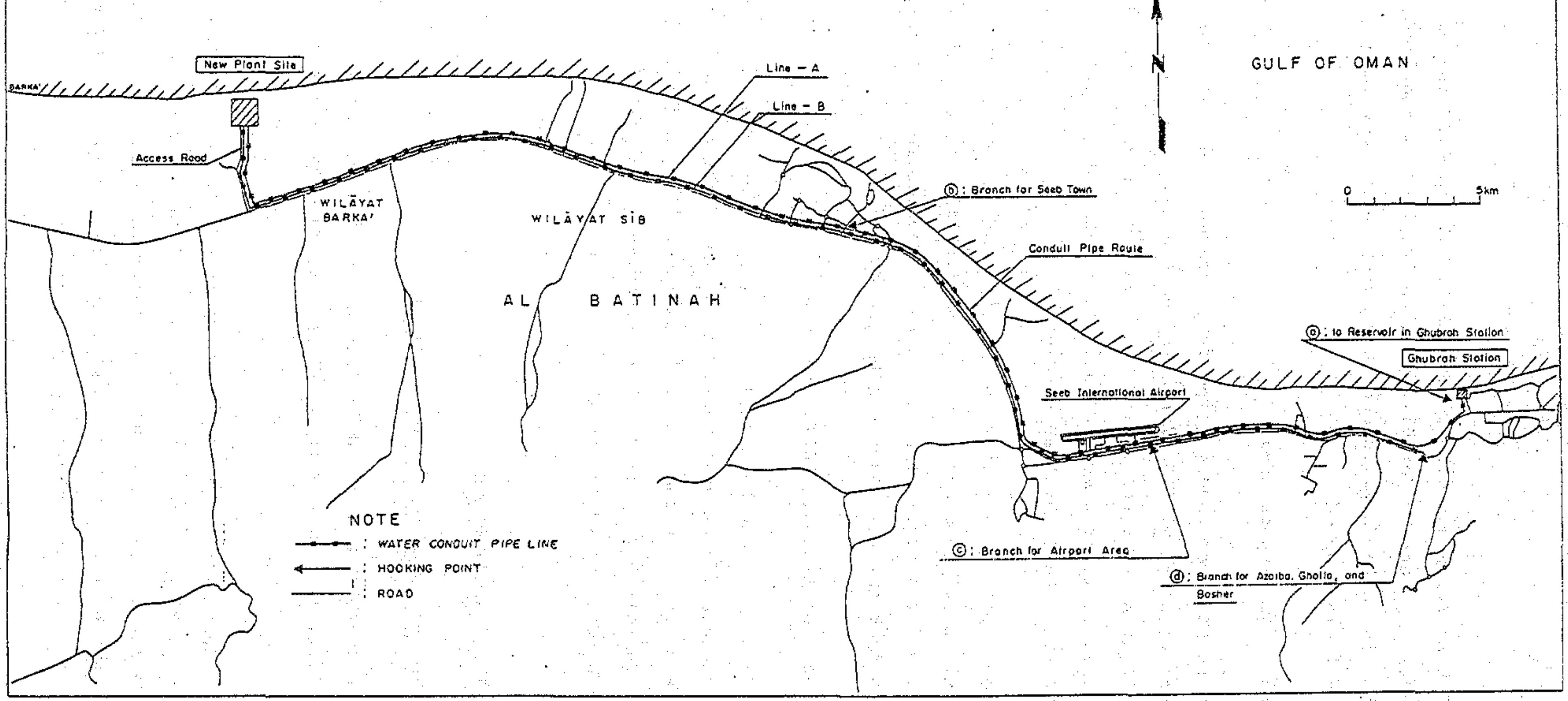
14.2 WATER CONDUIT ROUTE

14.2.1 Selection of Water conduit route

The water conduit route from the new plant site to Ghubrah Station is as shown in Fig. 14.1 and is to be along with the road between Muscat and Barka.

As to the approximate 4 km between the new plant site and Muscat-Barka road, the pipe is burried for approximate 2 km along with existing road and for approximate 2 km along with the new access road to new plant site. And, for the distance of less than 1 km near the interface point to Ghubrah Station, the pipe is burried in the wilderness.

Fig.14.1 WATER CONDUIT PIPE ROUTE



On the route along the Muscat-Barka road which is more than 90% of total conduit length, there is enough land space beside road to burry the conduit line, so it is advantageous to install the conduit line along with the road in the viewpoint of maintenance.

14.2.2 Terrain and soil conditions of water conduit route

The terrain is almost plain through main route, from Barka to Ghubrah except branch route, but it is essential to consider the following points on planning.

(1) Altitude

The highest point on the Barka to Ghubrah route is approximate 15 m above sea level, and Ghubrah Station which is terminal connection point is same level as the new plant site level (H.H.W.L. + 2m). And, both in the air-port branch area and azaiba branch area, there are approximate 80 m high areas above sea water level.

(2) Road crossing

Since there are 23 cross points of paved road on the water conduit route at the time of March 1985, the adequate erection method, such as jacking (driving) method is to be taken into account.

(3) Wadi crossing

It is necessary to take care on the bury method and protection method for scoring, for the about 20 points of wadi cross on the water conduit route.

(4) Soil condition

Through the route, surface layer's soil is sand or silty sand, and there may be no obstacle to bury the pipeline. However, it is recommended to carry out the survey test, such as test digging for the actual site work.

14.3 RESERVOIR AND PUMPING STATION

The flow diagram is shown in Fig. 14.2.

14.3.1 Reservoir

(1) Reservoir volume

The maximum storage volume of reservoir to be constructed in the plant site is determined as 216,000 m^3 that is 24 hours retention of the product water of desalination plant (180,000 m^3/d) plus the well water (Max. 36,000 m^3/d) to be mixed with the product water. By this volume, the fluctuation of plant operation mode and water flow rate is adjusted.

And, the reservoir volume is divided into 4 sections for easiness of operation and maintenance.

(2) Reservoir structure

The semi underground concrete structure which is easy in maintenance and is not affected with the ambient temperature is applied. The reservoir is furnished with ventilation and drain facility, and the bottom is to be sloped for water extraction.

(3) Reservoir specification

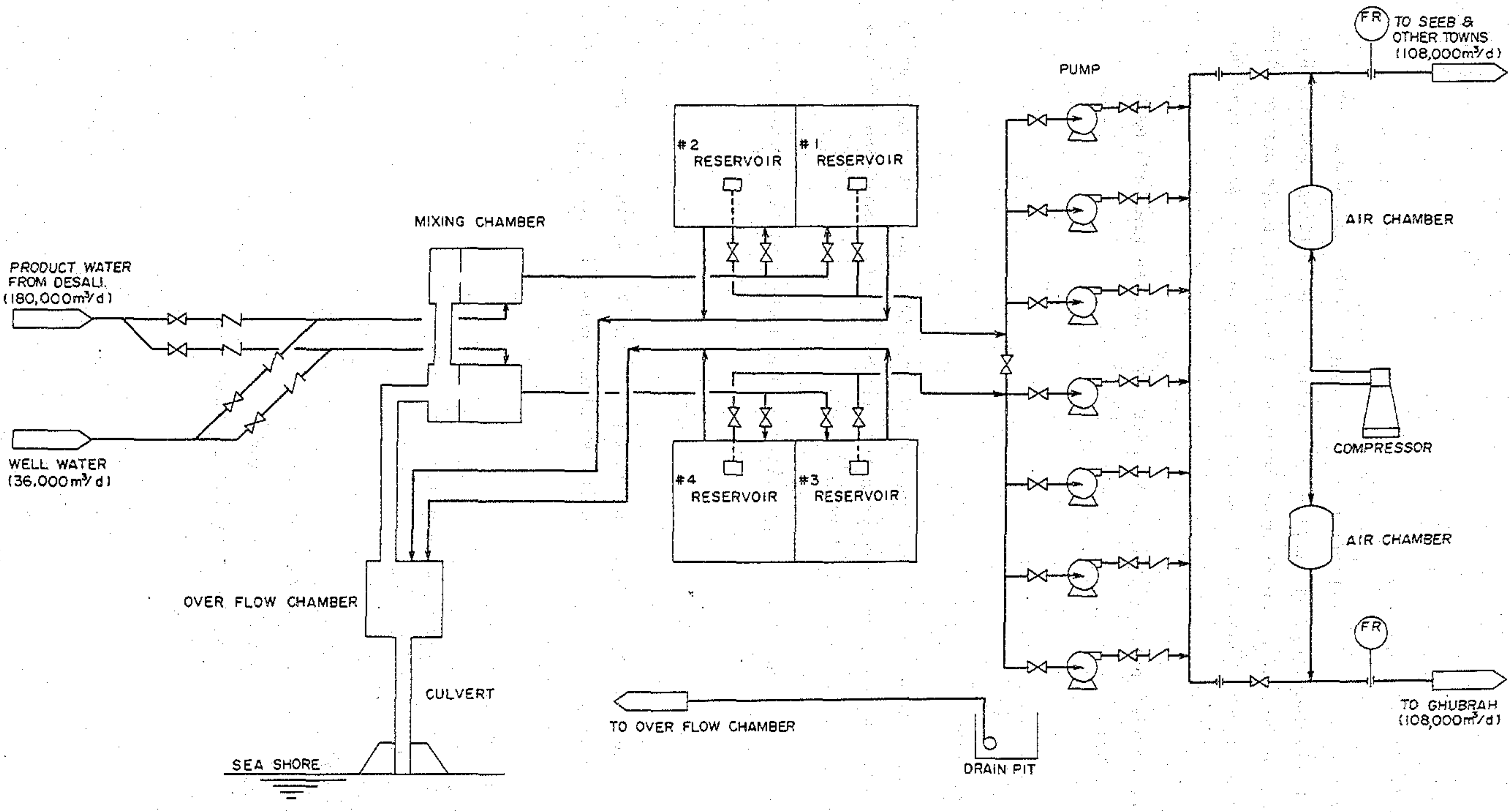
Storage volume	54,000 m^3 x 4 reservoirs = 216,000 m^3
Dimension (Width x Length)	84 m x 107 m each
Average depth	6 m

14.3.2 Mixing facility

(1) Mixing method

The desalination plant has product water treatment system, but in order to effectively utilize well water, the mixing tank is to be installed at the inlet of reservoir where the production water of plant and well water are mixed.

Fig. 14 . 2 RESERVOIR & PUMP STATION FLOM DIAGRAM



(2) Delivery water quality

This feasibility study is planned in the condition that a constant well water both in quantity and quality is supplied at the mixing chamber, but according to the variation of well water quality, it is necessary to adjust the mixing ratio or control the water quality from product water treatment system.

The water quality after mixing is to meet with OMANIAN STANDARD NO.8 DRINKING WATER.

14.3.3 Water pump

(1) Pump room

The underground pump room which contains 7 identical units of single stage centrifugal pump is arranged beside the reservoir. The pump room includes the operation room, electrical room and office.

And a overhead crane is to be installed in the pump room for maintenance purpose.

(2) Water pump

For adjusting variation of total pumping rate and maintenance of pumps, 7 units (6 units for running + 1 unit for stand by) of single stage centrifugal pump are utilized.

Specification (per 1 unit)

Type	; Single stage centrifugal pump
Capacity	; 27.5 m^3/min
Head	; 100 m
Revolution	; 980 rpm
Drive	; 750 kW Motor (Direct)
Material	; Casing : Cast iron
	Impeller: Stainless steel cast

14.3.4 Water conduit line

(1) 2-Lines system

Conceptual water conduit line is shown in Fig. 14.3.

In these long distance conduit plan, the flow rate variation and pressure variation of consumers influence on the operation point variation and delivery pressure variation of pumps.

And, in the case of 1-line, it is impossible to deliver any water, when an accident occurs in one pipeline. Then, 2-lines system is applied and some by-pass between each line are installed in order to avoid the risk and make possible to supply water to each other.

(2) Selection of material

The material of pipe is to be selected in taking account that it is long, it is important facility, resistivity is required and productivity and maintenability are to be considered.

Although the cement lined cast iron pipe, lined steel pipe, mortar pipe, plastic pipe, etc. are considered, the cement lined cast iron is applied, considering many references and reliability.

(3) Selection of pipe diameter and pump head

1) Line A: for Ghubrah station

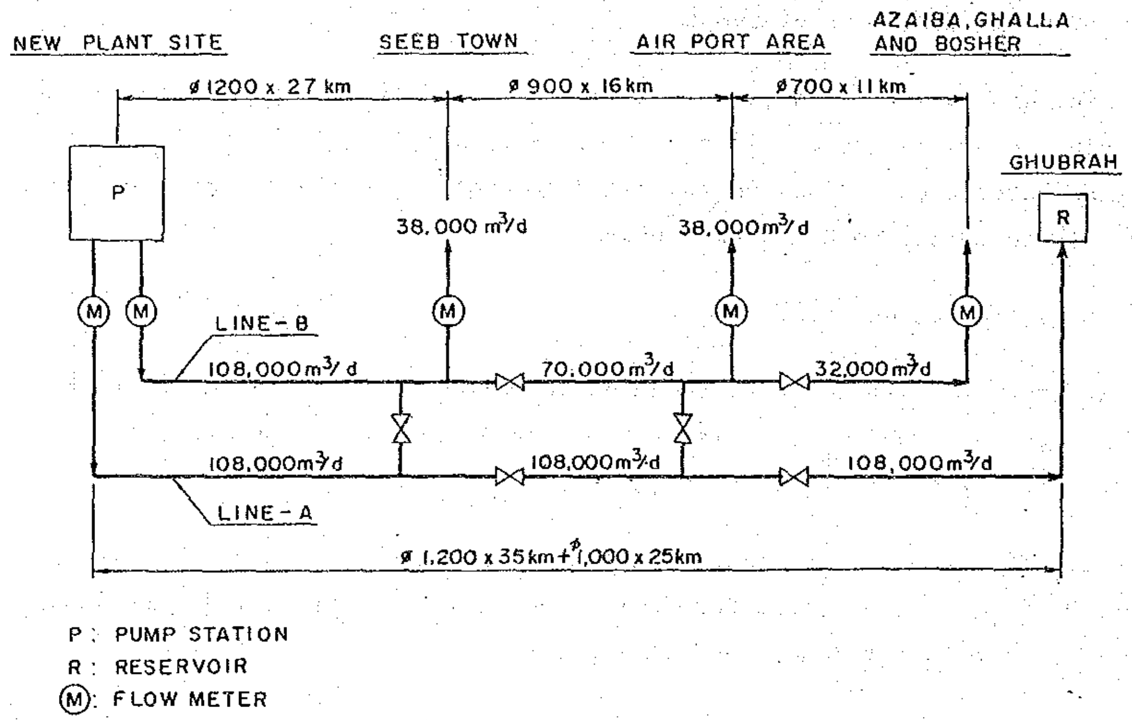
Pipe diameter of 1,200 mm (35 km length from Barka to Ghubrah) and pipe diameter of 1,000 mm (remaining 25 km length to Ghubrah) are selected in consideration of economical comparison of several pipe diameter and influence of water hummer.

2) Line B: for Seeb, Airport area, Azaiba, Ghalla and Bosher areas

Diameters are as follows.

New plant - Seeb branch	:	1,200 mm dia.
Seeb branch - Airport branch	:	900 mm dia.
Airport branch - Azaiba branch	:	700 mm dia.

Fig. 14. 3 Piping System Diagram of Water Conduit Line



In this case, the required pump head is about 100 m which is same as Line A, and the identical pumps can be applied. So it is beneficial in the point of operation and maintenance.

(4) Pipe specification

The major specification of water conduit line is as following.

Total pipe length	:	approximate 114 km
Pipe	:	Cement lined cast iron pipe (ISO 2531 K-9 T-type or JIS G-5526 T-type Class-3 or equivalent)
External surface	:	Tar epoxy + polyethylene sleeve, or polyethylene coat for the corrosive soil
Internal surface	:	Cement mortar lining

CHAPTER 15

OPERATION AND MAINTENANCE PERSONNEL

AND

TRAINING PLAN

CHAPTER 15 OPERATION AND MAINTENANCE PERSONNEL AND TRAINING PLAN

This Chapter deals with operation and maintenance personnel and the training plan given to the necessary personnel employed by MEW for the operation and maintenance of the power and desalination complex plant.

This Chapter also recommends the number of necessary personnel and the time at which these personnel become necessary, clarifies the personnel employment plan and recommends the education and training program to improve the knowledge and capability of the personnel and to perform the safe and economical operation and maintenance of the complex plant.

15.1 PERSONNEL PLAN

15.1.1 Administrative organization

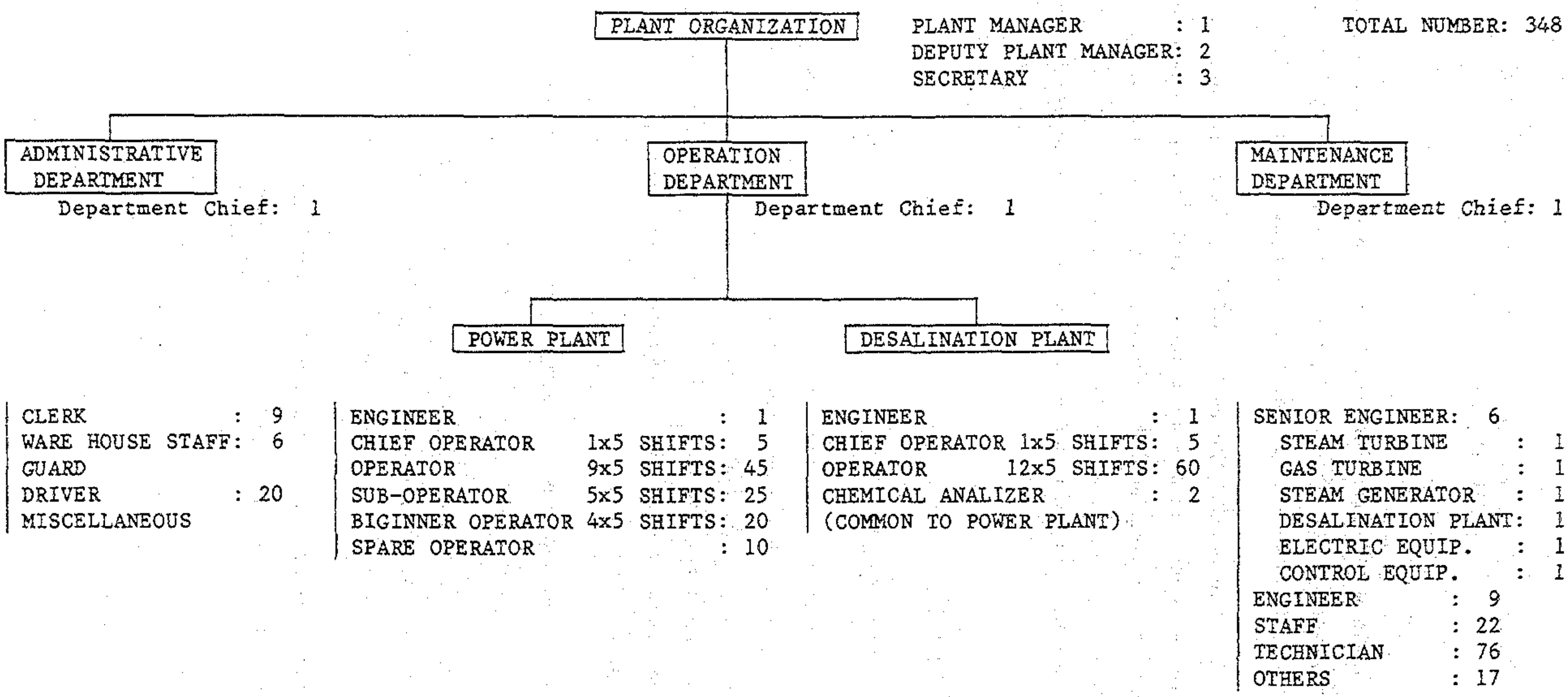
Under the plant manager, the top responsible person, the power and desalination complex plant has three organizations, namely, administrative department, operation department and maintenance department. Each department is operated under the direct command of a person assigned as the department chief. The operation department is divided into power plant division and desalination plant division.

Fig. 15.1 shows the management organization and the number of the personnel, which sums to 348 persons, at this plant.

Chief operators and operators is assigned to each shift team to operate the plant 24 hours by four shifts operation system. Therefore, this needs the formation of five shifts teams for each plant.

But, this table does not include the personnel engaged in daily miscellaneous work and the personnel necessary for the annual maintenance.

FIG. 15.1 MANAGEMENT ORGANIZATION OF POWER AND DESALINATION COMPLEX PLANT



15.1.2 *Job assignment of personnel*

The specific duties and responsibilities of the key personnel for the operation and maintenance of the power and desalination complex plant are as follows:

(1) Plant manager

Plant manager is the top responsible person at the job site for the safe and economical operation of the power and desalination complex plant.

(2) Deputy plant manager

Deputy plant manager assists and acts for the plant manager. Each one deputy plant manager is assigned respectively to the power plant and to the desalination plant and they virtually act as the responsible person for each plant.

(3) Operation department chief

Operation department chief is the person responsible for the control of the overall operation of the whole power and desalination complex plant. He is responsible for the safe and economical operation of the whole plant with the understanding of the basic theory and function of the devices, equipment and systems of whole plant.

(4) Operation engineer

Operation engineer is directly engaged in the actual operation. He is responsible for the safe and economical operation providing directly the shift operators with necessary directions having the understanding of the basic theory and practice of the devices, equipment and systems of each plant to which he is assigned.

(5) Chief operators

Chief operator provides the personnel with suitable directions working on the same shift with him, performs operation and monitoring, and records periodic monitoring and operation data for the plant to which he is assigned.

Therefore, it is essential that he has the full understanding of the construction and function of the devices, equipment and systems.

(6) Maintenance department chief

Maintenance department chief is the person responsible for the control of the overall maintenance of the whole power and desalination complex plant. He is responsible for formulating the basic directions on daily maintenance work, for counteractions in case of accident or breakdown, for periodic maintenance and for plant safety conservation with the understanding of the basic theory, function and capacity of the devices, equipments and systems installed at each plant.

(7) Maintenance senior engineer

Maintenance senior engineer performs the maintenance of the plant with responsibility. Each maintenance senior engineer is assigned to the following equipment respectively.

a) Gas turbine facilities
b) Steam turbine facilities
c) Boiler facilities
d) Desalination facilities
e) Electrical facilities
f) Instrumentation facilities

Each maintenance senior engineer in charge of the individual facilities gives guidance directly to the engineers under his direct control and performs daily plant maintenance work and undertakes repair work in case of accident or breakdown, in the field to which he is assigned. Therefore, it is requested that he has the sufficient knowledge and practical experience of disassembly, repair and assembly in addition to the full understanding of the construction and performance of the devices, equipment and systems installed at the plant.

(8) Chemical analyzer

Chemical analyzer mainly performs the periodic chemical analysis of the boiler make up water, boiler feed water and the water produced at the desalination plant and plans the safe plant operation and control.